Investigating the epidemiology of leptospirosis in urban slums through human mobility and environmental perception

by

Pablo Ruiz Cuenca

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Declaration

I, PABLO RUIZ CUENCA, declare that this thesis titled "*Investigating the epidemiology of leptospirosis in urban slums through human mobility and environmental perception*" and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

Signed: [redacted] ……………………………………

Date: 8th September 2025

Abstract

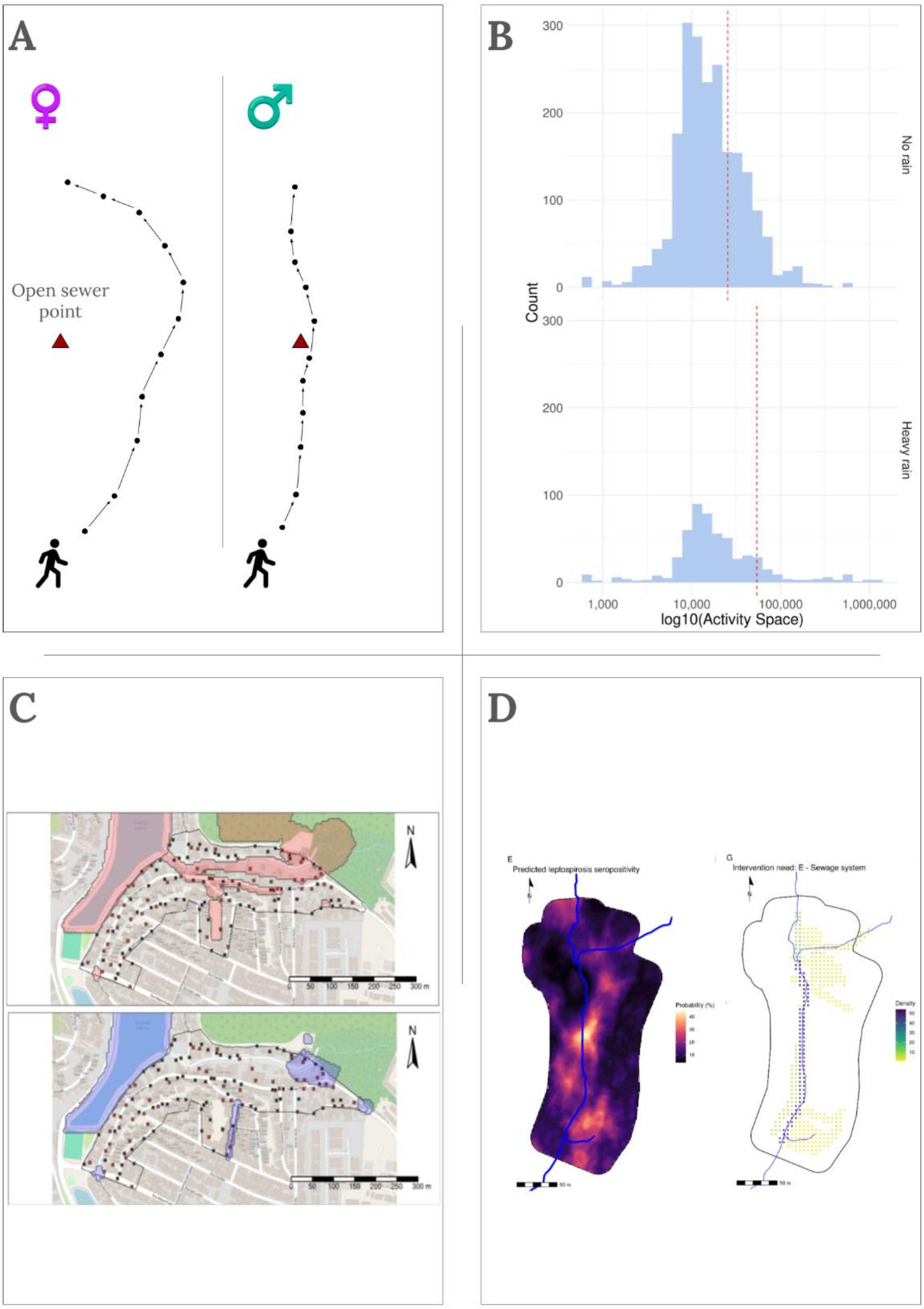
Leptospirosis is a zoonotic disease caused by infection with *Leptospira* bacterial species. Human infections occur after exposure to infectious urine, predominantly from rats. This urine is found in contaminated waters and muds in areas where rat populations are abundant. Therefore, leptospirosis is a disease with strong environmental drivers. Global estimates have attributed 1 million cases each year to leptospirosis, with 58 900 yearly deaths. It is therefore considered one of the leading causes of zoonotic disease in the world. There are some important factors of leptospirosis epidemiology that remain unclear. In this thesis, I have focused on two broad aspects: human mobility and environmental perception. The thesis is made up of four papers that show the work I carried out along with collaborating co-authors to examine how these aspects affect leptospirosis epidemiology in urban slums in Salvador, Brazil.

The first two papers use telemetry data collected using GPS loggers to analyse human mobility. We begin by examining how step selection functions, a spatio-temporal point process model used in animal movement ecology, can be used to analyse how individuals interact with their environments. We also consider how these interactions may vary across socio-demographic features like age and gender. This research shows that step selection functions were a useful tool to quantify human movement behaviours. The analysis also suggested that there were movement differences based on gender. Movement analysis was expanded in the second paper, where we take a more in depth look at various movement characteristics. We examine how these movement behaviours vary across individual characteristics and daily characteristics, such as rainfall. Our research shows that gender differences in movement behaviours may not follow expected patterns. It also provides a strong foundation to research the effects of rainfall on human movement behaviours..

In the following two papers we used collaborative mapping to capture people's perceptions of their environment. Collaborative mapping is a type of participatory research method that involves individuals in the map creation process. Through this, we are able to obtain their perceptions on various aspects of their environment. In the third paper, we ask residents to identify areas that they consider risky for their community's and their own health. We also ask them to classify these areas into various categories. We then used these perceptions to compare them to objective measures of

comparable risks. We found there was a low perception of leptospirosis as a health risk and that residents more easily identified visible risks, such as rubbish piles. For the fourth paper, we collected individuals' perceptions on where interventions should take place in their neighbourhoods. We compared these areas with a prediction for leptospirosis seropositivity, created using household leptospirosis data. Residents' intervention requests clustered around the communities' stream rather than the predicted leptospirosis hotspots. Both these pieces of research highlight areas of knowledge that could be improved and disagreements on what interventions should occur and where.

Overall, this thesis presents innovative ways to use existing methods to analyse data in the broad context of infectious disease and, more specifically, leptospirosis. The results presented can be used to guide public health interventions and how to assess them. They also present a foundation for further research to build upon to understand the mechanisms of leptospirosis infections in high prevalence, low resource settings.



Summary Figure A: Paper 1 suggests that women may be avoiding open sewers compared to men. B: Paper 2 shows people have higher activity spaces during heavy rainfall days than during no rainfall days. C: Paper 3 highlights there is disagreement between where residents believe there is high risk of rats (red areas) and where rats were trapped (red squares). D: Paper 4 shows residents' intervention requests cluster around the stream instead of around predicted leptospirosis hotspots.

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Contribution: Conceptualisation, formal analysis, investigation, methodology, data curation, software, visualization, writing (original draft, review and editing).

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Contribution: Conceptualisation, Data Curation, Formal analysis, Investigation, Methodology, Software, Visualisation, Writing (original draft, review and editing).

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Chapter 1 Introduction

Zoonoses are increasingly becoming a public health issue. Factors contributing to this include rapid urbanisation of the global population, increasing growth of cities into previously undeveloped land and climate change, amongst many others. The one health concept has gained more attention as a tool to investigate zoonotic diseases, considering human, animal and ecological factors. Leptospirosis is one of the leading disease-causing zoonosis worldwide.[1] This rat-borne infection is endemic to tropical and subtropical regions and is considered a disease of epidemic potential, especially following heavy rainfall events and flooding. Control, prevention and research strategies for leptospirosis benefit from a one health perspective to fully consider all aspects of the disease process.

1.1 Leptospirosis

1.1.1 Biological characteristics

Leptospirosis is caused by an infection by bacteria from the genus *Leptospira.* These bacteria are free-living, obligate aerobic spirochetes with a characteristic hook (Figure 1.1). The genus is made up of species that have been traditionally classified into pathogenic, intermediate or saprophytic (non-pathogenic), although new research has proposed using more pathogenic-agnostic terms. [2] These clusters are subdivided into serovars based on the antigenic expression on the surface of the bacteria. There are a total of 13 pathogenic species, with over 260 serovars currently identified. The most common species found in human cases is *Leptospira interrogans*, which is subdivided into various serovars. Some of the serovars are strongly associated with specific animal reservoirs, such as the *canicola* serovar in dogs or the *copenhageni* serovar in rats, although this association is not absolute. [3] Leptospires are able to infect most mammals, including aquatic mammals.[4] However, the most common carriers are domestic animals, such as cows and dogs, and rats. The importance of the animal carrier varies depending on the environmental context, with cows playing a key role in disease maintenance and transmission in rural regions and rats filling that role in urban areas.[5] Humans are considered accidental hosts.

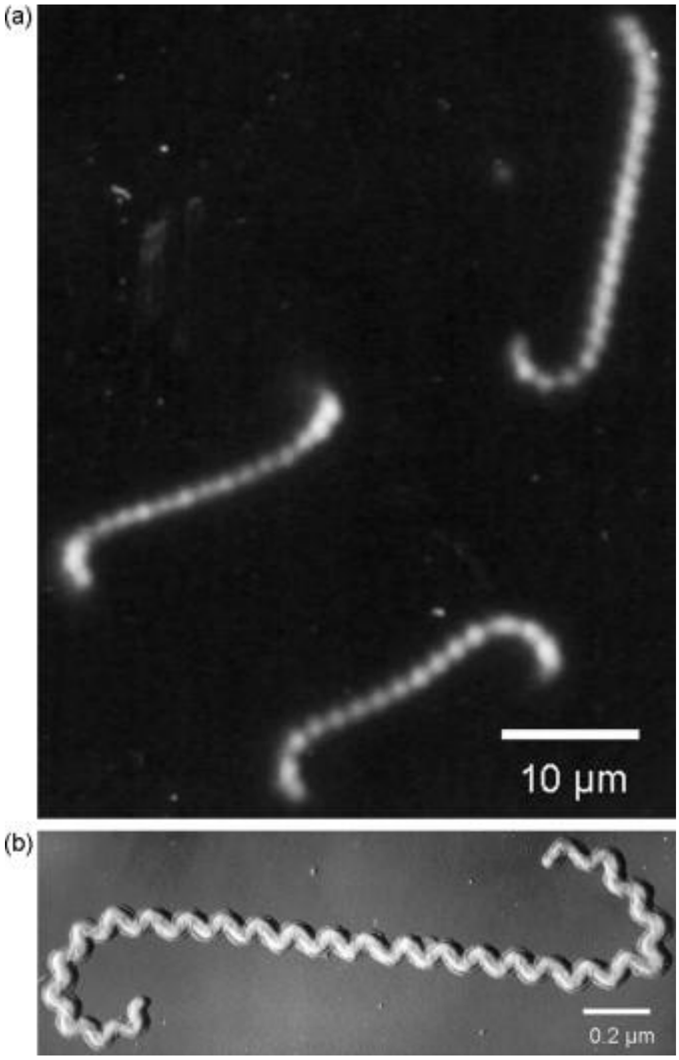


Figure 1.1 Dark field (a) and shadowed electron (b) images of Leptospira species (from Adler et al, 2015[6])

1.1.2 Clinical and immunological aspects of disease

Infection in humans occurs after exposure to contaminated environments, allowing leptospires to enter the body through micro-cuts or mucous membranes. These environments are often waters or mud that have been contaminated by animal urine. The incubation period is on average 7 days long, although it can be as short as 2 and as long as 30[3,5,6]. A spectrum of symptoms can appear ranging from mild to severe, including fatal presentations. Sub-clinical infections are also possible, causing no obvious symptoms in the infected.

Mild symptoms include headaches, fever and myalgia (muscular pain). These may be serious enough to have a significant impact on infected patients, affecting social and economic opportunities. Given the non-specific symptoms, leptospirosis can often be misdiagnosed as other febrile diseases such as flu, malaria or dengue. This results in under-reporting of cases, which can also affect treatment efficacy. More severe symptoms include renal failure, liver failure, jaundice and pulmonary oedema and haemorrhage. The combination of jaundice and renal failure is known as Weil's disease and is one of the most recognizable forms of the disease, first described in 1886.[7] The pulmonary presentation is called severe pulmonary haemorrhage syndrome and is commonly seen in epidemic situations, often following climate disasters.[3] Case fatality rate can vary between 5 – 15%, although the more severe cases can reach a fatality rate of 70%.[1,3,8]

Infections cause a strong humoral response. This immune response is thought to be modulated by the infecting serovar, although the exact pathway for how this occurs and what other factors influence it still remain unknown.[5,6] These antibodies appear to provide some protection against homologous serovars.[9] However, studies have also shown that previous hospitalisation for leptospirosis increased the risk for repeated infection with leptospirosis, showing that reinfection is possible.[10] Duration of antibody positivity has been estimated to last an average of 8 years.[11] Although antibody positivity does not necessarily encompass all immune protection, as there is a cellular immune response involved, it allows us to quantify how long immunity may last for. Vaccination against leptospirosis in humans is an active area of research. The first vaccine to protect against leptospirosis in humans was used between 1919 and 1921, in a group of coal miners in Japan.[12] Since then, advances have been made in human vaccines to attempt to reduce side effects and increase cross-reactive immunity between serovars.[3,6] However, this remains a challenge and limits the usability of vaccines as an effective control measure. No human vaccines have progressed to large-scale clinical trials.[5]

Leptospirosis can be diagnosed by detection of bacteria or its components using PCR, isolation of bacteria in cultures or detection of specific antibodies (serodiagnosis). The first two methods are not widely used given the technical challenges of performing PCR tests and maintaining cultures, especially in resource-limited scenarios. Therefore, most cases are diagnosed using serology. Serodiagnosis can be broadly divided into two categories: genus-specific tests and serovar-specific tests. The microscopic agglutination test (MAT) is the gold-standard diagnostic method, as defined by the WHO.[8] This test uses live antigen suspensions of specific leptospirosis serovars, which are used against patient's serum samples. The result shows the highest dilution of serum that produces a 50% agglutination. Different cut-off points can be used to determine if a sample is positive or negative. The MAT has high specificity, which is helpful in a public health context. Other serological test such as ELISAs can be used to detect IgM antibodies. However, these test do not provide information on the infecting serovar and have also had issues with cross-reactivity with other pathogens.[3,6]

Most mild cases of leptospirosis tend to resolve without treatment. Early treatment is helpful to avoid progression to more severe forms of the disease. However, clinical identification of the disease, which is the main method for diagnosis in early stages given the limited rapid diagnostic tests available, can be challenging in tropical regions where other febrile diseases are also endemic. Treatment with antibiotics such as doxycycline in early suspected cases is common and recommended.[8] Hospitalised cases require more intensive care with intravenous antibiotics and supportive care.[5] Acquired antimicrobial resistance in leptospires is uncommon. Therefore, sensitivity tests for treatment are not used.[13] Prevention of exposure to contaminated environments remains one of the best control methods to avoid infections.

1.1.3 Epidemiology

1.1.3.1 Global epidemiology

A global morbidity and mortality study of leptospirosis estimated that the disease causes over 1 million cases each year across the world. This study also attributed an estimated 58 900 yearly deaths to the disease.[1] The bulk of these cases occur in tropical regions, specifically affecting urban vulnerable populations (Figure 1.2). Although it was traditionally seen as a rural disease, associated with strong interactions with domestic animals such as cows and regular exposure to flooded areas, the disease is now considered an urban public health issue.[1,5,14] Population shifts towards cities and surrounding areas along with poorly managed urban growth and low investments in sanitation infrastructures of peripheral communities have been key factors in the emergence of leptospirosis as a public health issue in these areas.

In Brazil, where the research presented in this thesis is focused on, leptospirosis is considered an endemic disease with epidemic potential during rainy seasons. Yearly confirmed cases have ranged between 3000 to 5000 individuals, as reported by the Ministry of Health since 2007. There was a significant dip in cases in 2020 and 2021, likely due to the COVID-19 pandemic. Case fatality rates have had small fluctuations around the 9% mark.[15]

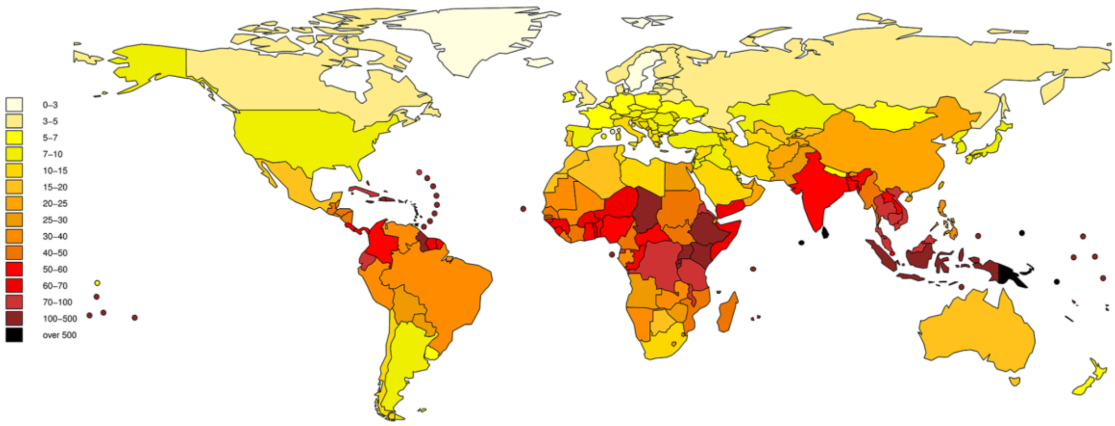


Figure 1.2 Global burden of leptospirosis (from Torgerson et al, 2015 [14])

Risk factors

Leptospirosis is associated with a number of socio-demographic and environmental factors. Across studies performed in various regions, men have shown a higher risk of infection than women, which could be attributed to cultural differences between genders. Additionally, older adults have higher risk for infection. Socio-economic factors, such as illiteracy and poor housing, have also shown strong associations with leptospirosis. Heavy rainfall and contact with mud and flood waters have also been linked to increased risk.10,16–18 Overall, this defines leptospirosis as an environmentally driven disease which is particularly related to poverty.

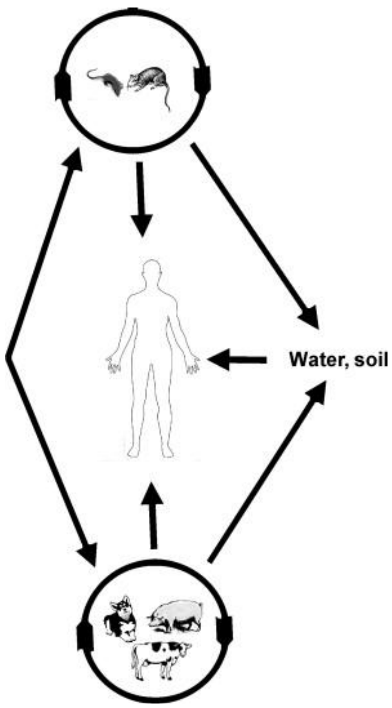


Figure 1.3 Leptospirosis transmission diagram (from Adler et al, 2015[4])

1.1.4 Intervention study

Three of the four papers presented in this thesis–chapters 2, 3 and 5–are embedded into an intervention study taking place in Salvador, Brazil.[19] This study is assessing the effects of a two-pronged intervention on the risk of leptospirosis infection for residents. The intervention includes structural changes to the sewage system, implementing a simplified system which receives the sewage waste from a group of households instead of from single dwellings, and community engagement. The second aspect of the intervention is focused on giving residents a voice in decision-making regarding the sewage policies and involving them in research activities.

The study follows a matched quasi-experimental design, using non-randomised intervention and control clusters. These clusters are matched by environmental and social characteristics. Participants were recruited before the intervention started, representing the baseline period, and followed up roughly every 6 months.

1.1.5 Knowledge gaps

There are many aspects of leptospirosis that still remain unknown. The research in this thesis focuses on trying to uncover evidence on two aspects of the disease. The first aspect is how movements through local environments may affect exposure to leptospirosis. Although it is known that there are strong associations between infection and the environment surrounding people's houses, it remains unclear if infectious exposure is happening in households or around the community. Analysing movements may help to have a clearer picture of how exposure to contaminated environments occurs. The second aspect is how residents perceive their surrounding environments, with a particular focus on environmental risk factors for leptospirosis. Capturing and analysing this data is important to, firstly, provide a voice to people who are often under-represented in public health research, and secondly, understand how perceptions of the surrounding environment vary. Together with understanding movement behaviours, both of these aspects can be useful in designing and implementing interventions. They make local knowledge accessible to public health authorities and highlight which areas need improving.

1.2 Primer on methods

Each chapter of this thesis includes an extensive description of the methods used for each particular analysis. However, I have included a primer on key methods below.

1.2.1 Human mobility

Research into human mobility has been increasingly gaining attention in the context of epidemiology, especially in infectious disease epidemiology. There are many ways that mobility data can be captured. At coarser scales, looking at mobility within or between countries, useful datasets include Google location history or cell tower data.[20–22] However, one of the issues with both these datasets is that they are inherently anonymous. Limited individual-level characteristics can be extrapolated from the data, such as socio-economic factors[23,24], but other important epidemiological variables like age or gender are inaccessible.

GPS loggers can be used to overcome this challenge. By supplying the devices to specific individuals, the data collected, a type of telemetry data, can be linked to any information that the individual has consented to provide. The size and weight of these devices mean they are easily carried around by participants and don't interfere with their daily activities. The GPS loggers are programmed to record locations at predefined time intervals. Battery life is substantial, meaning that these devices can be used to record movement over multiple consecutive days. The resulting data provides a rich picture of an individual's movements over the period of collection, which can be used to analyse various movement characteristics such as distance travelled or environmental interactions.

1.2.2 Animal movement research methods

The study of animal movements to understand where they spend their time and how they use their surrounding environment has a long history in ecology. With advances in quantitative tools, new methods have been developed to make use of various types of data, including telemetry data. These methods can be broadly divided into three categories: 1) space use, including methods used to understand home ranges of animals, 2) resource selection, questioning how an animal moves given the environmental features surrounding them, and 3) resource utilization, combining concepts from both of the previous categories in a two-stage process to understand environmental use given the space use of an animal. All three categories use spatial point process models to analyse different outcomes, using these statistical models in various ways to analyse the data. There are many benefits and drawbacks to each type of method discussed extensively in the literature which we will not touch upon given the scope of this thesis.

1.2.3 Step selection function

Step selection functions originate from animal movement ecology and are used to understand how animals chose, or select, specific factors of their environment when moving through them.[25,26] In its essence, it a spatio-temporal point process model where an individual's location is conditioned on their previous location, the environmental factors present there and where the individual could have travelled to instead. It falls within the umbrella of resource selection models in ecology and utilises telemetry data, often collected using GPS loggers. The data is made up of consecutive locations collected at pre-defined time intervals, representing the movements of an individual through space.

This method of analysis firstly captures the movement characteristics of an individual, namely their step lengths and turning angles. The step lengths are the Euclidean distance between two consecutive locations, whilst the turning angle represents the angle of divergence from one recorded point to the next. The parameters are then used to create a set of available steps for each used step. These available steps are biologically plausible and represent locations that an individual could have travelled to but did not. The environmental characteristics present at the used steps are compared to those at the available steps, using a conditional logistic regression which assess the odds of a step being used. This produces a set of selection coefficients for each of the environmental factors included in the model. These selection coefficients represent the relative likelihood of choosing the observed locations over alternative locations, based on the specific environmental factor.

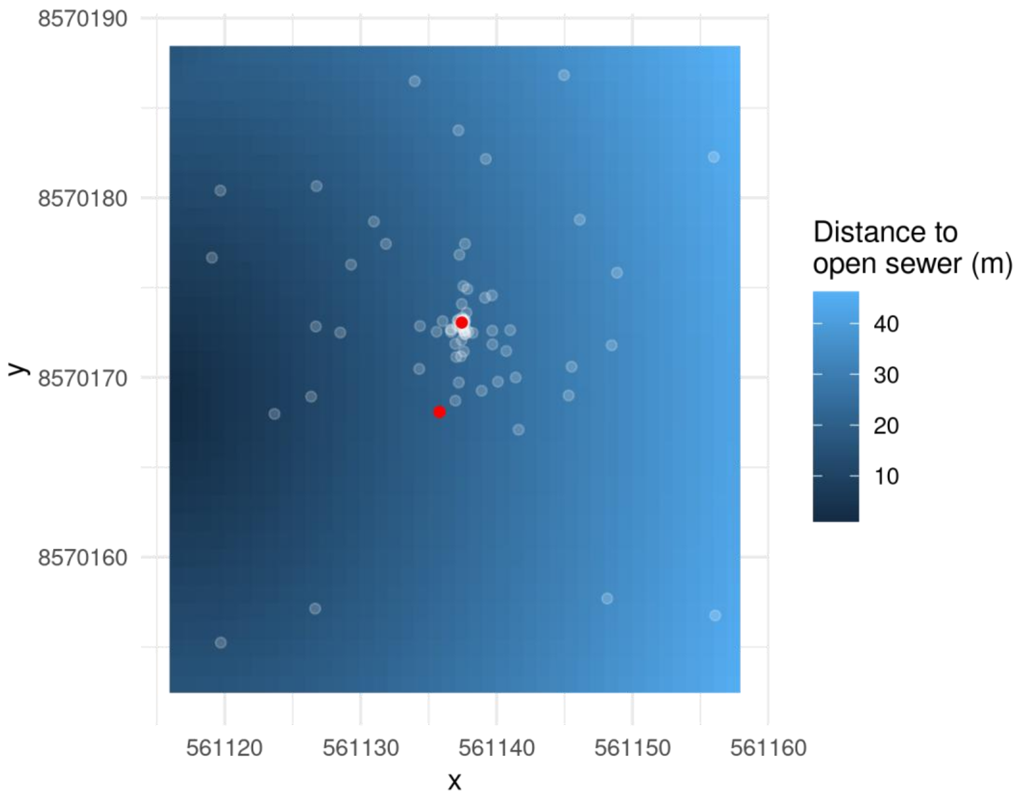


Figure 1.4 Step selection functions take observed steps (red dots) and create available steps (grey dots) that represent biologically plausible steps that an individual could have taken.

One of the biggest benefits of this model is that it can help to model movement choice. By creating a set of alternative locations, we can gain some understanding of what factors could be affecting the individual's movements. It is important to highlight here that there are many factors that can influence an individual's choice and behaviours, and that the relationships between these are likely complex. The models presented here are not attempting to fully explain all of these relationships. Instead, the intention is to shed some light on how environmental features may be altering movements. Another important benefit of step selection models is that they allow flexible use of rasters in the models. This allows for creative uses of environmental rasters, which can assess these factors in multiple ways.

An important limitation of these models is that the result can be conceptually difficult to understand. We presented them in the odds ratio format given the epidemiological context of the research. However, as mentioned above, the exact framing of these values is somewhat abstract and requires appropriate communication to avoid oversimplifying them. Another limitation is the underlying assumptions that are made with the use of step selection functions, which may be violated in their use for human mobility analysis. Firstly, we assume that by including step lengths and turning angles as variables in the model we are sufficiently adjusting for intentional movement towards a destination. Secondly, step selection functions assume that movement is smooth, by relying on autocorrelated distributions of movements. This may be violated in urban areas, where street layouts may force people to have sharp-cornered movements. We believe that the violation of this assumption does not affect the overall results, but further methodological research which is outside of the scope of this thesis is needed to fully investigate this.

1.2.4 Collaborative mapping

Collaborative mapping is a type of participatory research which allows residents' local knowledge to be integrated into Geographic Information Systems (GIS). This mixed-method approach involves reaching out to communities to ask specific space-based questions, aided by maps of the local area.[27] The community members are able to draw on these maps, which are then used to digitalise their answers into spatial data. These data can then be used in technical analyses. Collaborative mapping is a powerful tool that allows contribution by people who are often under-represented and overlooked in research. This method has been used to research a range of topics, from air and noise pollution [28] to food insecurity [29].

In the context of public health and epidemiology, it has been used as a tool to understand specific aspects of a range of diseases. In Mozambique, it was used by Lequechane et al.[30] to capture potential mosquito breeding sites for malaria control programmes. They asked residents of a local community to map where they thought mosquito breeding sites were present and classify them into permanent or temporary. Collaborative mapping was also used by Green et al [31] in a low-resource setting in Kenya to create a map of the local area, which was previously unavailable, and capture where youths displayed behaviour which could increase their risk of becoming infected with HIV. In both of these examples, the environment played an important role in outcome, and collaborative mapping allowed researchers to collect people's perceptions of how this mechanism worked.

Collaborative mapping for leptospirosis research is an important tool to understand how the environment may affect an individual's perception and behaviours. Given that there is a high burden of leptospirosis in lower socio-economic communities, using participatory methods helps to uncover local knowledge that may be neglected by traditional sources of information. It also creates stronger bonds between the communities and the research teams, ensuring cooperation for other ongoing projects.

1.3 Structure of the thesis

This thesis is made up of four scientific papers, which cover two main areas of research: human mobility and spatial perceptions. The papers are presented in thematic order. Given that some of my key contributions are presented in the respective supplementary materials, these are included at the end of each paper.

The first paper presents integrated step selection functions as a new method to analyse fine-scale human mobility data in the context of leptospirosis epidemiology. We used data collected by GPS loggers in four low-income neighbourhoods of Salvador, Brazil. We combined this data with known environmental risk factors for the disease. We then proceeded to assess how integrated step selection functions can be used to analyse differences in movement behaviours, based on individual-level factors such as gender or leptospirosis seropositivity. In the paper we discuss how the results can be interpreted, along with the strengths and limitations of using this novel methodology.

The second paper takes a deeper look at human mobility in these neighbourhoods. In this paper, we used more telemetry data, collected using GPS loggers over two periods of time in each study area. These periods represent the baseline and first follow up phases of an on-going intervention study. We revisited and expanded the research carried out by Owers et al, 2018 [32], focusing on how much time people spend at home, how far they travel, how much space they use and their interactions with specific environmental factors. We apply a set of movement analysis methods, including integrated step selection functions. The paper discusses our findings in the context of leptospirosis epidemiology in Salvador and in the broader context of urban tropical areas.

The third paper presents collaborative mapping as a tool to capture residents' perceptions of spatial risk in their neighbourhoods. We analyse these perceptions by comparing them to objective measures of comparable risk factors. This paper shows how these spatial perceptions can be incorporated into infectious disease epidemiology research to assess local knowledge of risk, as well as highlighting areas for targeted interventions.

The fourth paper uses collaborative mapping to collect where residents believe that interventions should take place in their communities. We focused on a number of structural interventions aimed at improving the environmental health of the communities and reduce exposure to infectious diseases, including leptospirosis. These perceptions were compared to the results of a statistical model, used to create a spatial prediction of leptospirosis risk across the neighbourhoods. This paper highlights the differences between residents' perceptions of community issues and the targets of local government interventions. It also shows how qualitative measures can be combined with quantitative methods.

Chapter 6 is a concluding general discussion where we provide an outline of the main contributions and limitations from each paper. We also explain what future research could be carried out building upon the findings of this thesis.

Chapter 2 Using step selection functions to analyse human mobility using telemetry data in infectious disease epidemiology: a case study of leptospirosis

Pablo Ruiz Cuenca[1] , Fabio Neves Souza[2,3] , Roberta Coutinho do Nascimento[3], Ariane Goncalves da Silva[2] , Max T. Eyre[4] , Juliet O. Santana[2,3] , Daiana Santos de Oliveira[2,3] , Emile Victoria Ribeiro de Souza[2] , Fabiana Almerinda G. Palma[2] , Diogo César de Carvalho Santiago[2] , Priscyla dos Santos Ribeiro[5,6] , Jonathan M. Read[1] , Cleber Cremonese[2] , Federico Costa*[2,3,7] , and Emanuele Giorgi*[1]

** These authors contributed equally to this work.*

1 Centre for Health Informatics, Computing, and Statistics (CHICAS), Lancaster Medical School, Lancaster University, United Kingdom

2 Institute of Collective Health, Federal University of Bahia, Salvador, Bahia, Brazil

3 Instituto Gonçalo Moniz, Fundação Oswaldo Cruz, Ministério da Saúde, Salvador, Bahia, Brazil

4 Environmental Health Group, London School of Hygiene and Tropical Medicine, London, United Kingdom

5 Federal University of Bahia, National Institute of Science and Technology in Interdisciplinary and Transdisciplinary Studies in Ecology and Evolution, Salvador, Brazil

6 Amsterdam University Medical Centre, Leptospirosis Reference Center, Medical Microbiology and Infection Control, Amsterdam, Netherlands

7 Department of Epidemiology of Microbial Diseases, School of Public Health, Yale University, New Haven, CT, United States

2.1 Abstract

Human movement plays a critical role in the transmission of infectious diseases, especially those with environmental drivers like leptospirosis—a zoonotic bacterial infection linked to mud and water contact. Using GPS loggers, we collected detailed telemetry data to understand how fine-scale movements can be analysed in the context of an infectious disease. We recruited individuals living in urban slums in Salvador, Brazil to analyse how they interact with environmental risk factors such as domestic rubbish piles, open sewers, and a local stream. We aimed to identify differences in movement patterns inside the study areas by gender, age, and leptospirosis serological status. Step-selection functions, a spatio-temporal model used in animal movement ecology, estimated selection coefficients to represent the likelihood of movement toward specific environmental factors. With 128 participants wearing GPS devices for 24 to 48 hours, recording locations every 35 seconds during active daytime hours, we segmented movements into morning, midday, afternoon, and evening. Our results suggested women moved closer to the central stream and farther from open sewers compared to men, while serologically positive individuals avoided open sewers. This study introduces a novel method for analysing human telemetry data in infectious disease research.

Keywords: Leptospirosis, human movement, GPS, urban health, infectious diseases, zoonosis

2.2 Introduction

GPS loggers are a growing tool for capturing both human and animal movements.[32,33] These small devices can be worn by individuals and record locations at regular preset time intervals. Compared to other methods of collecting human movements, such as cell tower traffic or Google Location History which are suited for analysing large-scale mobility,[20,34] these devices can capture very fine-scale movements. These data are crucial in quantifying exposure within complex environments, where terrain can change rapidly. Furthermore, movements recorded by GPS loggers can be assigned to specific individuals. This allows linkage between individual socio-demographic factors and the data collected, especially convenient when performing epidemiological analyses. Other methods for measuring human mobility are inherently anonymous and do not allow this connection to be made. An important challenge when using GPS loggers is that they rely on individual compliance for carrying the device at all times, an issue which is overcome by the other methods mentioned above.

The analysis of human telemetry data is an emerging field of research in epidemiology. Whilst previous methods have advanced this area of research, improvements could be made. For example, the methods used by Owers et al, 2018.[32] to assess the relationship between urban slum residents' movements and the risk of leptospirosis infection were able to analyse differences between genders, but did not consider other important socio-demographic factors. In another study, Fornace et al, 2019.[33] used GPS loggers to assess human exposure to mosquito vectors of *Plasmodium knowlesi* malaria and environmental factors associated with this. Various individual-level factors were included in the analyses performed in this paper, questioning how these could affect participants' movements. However, by not including comparisons of possible choices an individual could have made, this study could not determine how the environment may have influenced movement.

Leptospirosis is a zoonotic bacterial infectious disease with strong environmental drivers. It has been estimated to cause over 1 million yearly human cases worldwide, leading to 58 900 deaths.[1] Rats are the main reservoir of the disease, shedding bacteria in their urine.[35] Human infection is associated with exposure to contaminated waters and soils.[35–37]Evidence shows that in urban slum settings, men have a higher infection risk than women.[10] This has been attributed to differences in behaviours, especially in how individuals move through their communities, rather than a biological differences. Indeed, there is evidence that men tend to visit much larger areas during their daily journeys than women.[32]

Exactly where people are most exposed to high leptospirosis contamination, and therefore where infection is most likely to occur, has not been investigated. Previous studies have focused on the assessment of the peri-domiciliary environment and its associations to infection risk.[10,36,37] However, these analyses assume people are mostly exposed to infection risk in this area and ignore the exposure that individuals may incur when they move further away from their households. Furthermore, people's movement patterns may differ depending on individual socio-demographic factors which could in turn affect their risk of exposure. If individuals traverse highly contaminated areas where the risk of exposure is heightened, it can lead to an increased risk of infection. This is particularly important in environmentally heterogeneous areas, such as urban slums, where the landscape can change drastically in small spaces. Technological advances now allow us to record and analyse fine-scale movements to understand how these may affect infection risk.

In this paper, we developed a modelling framework to understand how telemetry data can be used to identify and quantify determinants of human movements, adapting methods from animal movement ecology. We present a novel method for analysing telemetry data to estimate environmental selection as individuals move through their urban communities. This method is applied in a low-income urban setting in Salvador, Brazil, and is used to examine how individuals interact with various key points in their surrounding environment . Furthermore, we analyse if there are any differences in movements inside the study areas between genders, ages and leptospirosis serological status. This method of analysis overcomes limitations from other studies by, firstly, specifically modelling choice of movement in relation to environmental factors and, secondly, incorporating multiple socio-demographic factors which allows regression relationships to be jointly adjusted for these.

2.3 Methods

2.3.1 Study areas

This study was nested in a prospective cohort study taking place across Salvador, Brazil.[19] Salvador is the third largest city in Brazil, located in the north-eastern region of the country and has a tropical climate. The study areas are considered urban slums (locally called `favelas`). They were selected for a number of reasons: firstly, they all have similar demographic and socio-economic factors within their populations; secondly, they all have a stream running through the centre of the community, which is considered contaminated; and thirdly, there is a high burden of leptospirosis in these populations.

All four study areas are small, with an approximate size of 0.03 km2. They are located across the outskirts of Salvador (Figure 2.1). The communities have very heterogeneous environments, with rapid changes in both land cover and slope. Buildings in these communities have been built with limited or no urban planning. They can be of varying quality, ranging from gated areas with multiple dwellings protected from rain and flooding to single brick buildings with informal entryways.

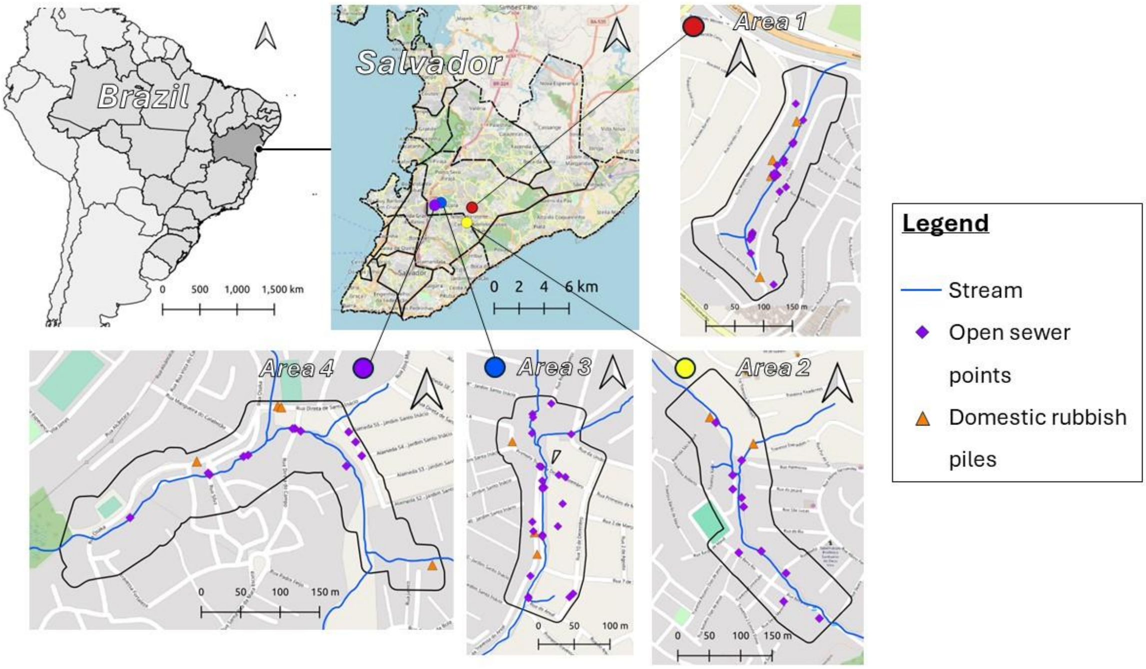


Figure 2.1 Map showing location of each study area in Salvador. Each area includes symbology for stream (blue line), open sewer points (purple diamond), and domestic rubbish piles (orange triangle).

2.3.2 Individual characteristics

The eligibility criteria for inclusion in the study was: individuals who (1) had been living at one of the study areas for at least 6 months, (2) slept there at least 3 nights a week, (3) were at least 18 years old and (4) gave written consent.[19] Participants were asked to answer a baseline survey which collected their demographic, social and economic characteristics, including age and gender. A blood sample was taken from each participant to determine serological evidence for *Leptospira* infection using the microscopic agglutination test (MAT), the standard test used for leptospirosis diagnosis.[35] In this analysis, a MAT showing antibodies with a titre >1:50 against any

Leptospira serovar was considered a positive result. Further details about the laboratory work carried out are available in Supplementary Material I. The location of their household was recorded and georeferenced by the research team.

Participants who were already enrolled in the cohort study were recruited to take part in the movement analysis study. At the time of recruitment, we found no published scientific studies detailing how to perform sample size calculations for research using GPS data in humans. Therefore, we opted to use convenience sampling instead. A target of 30 people per study area, balanced by gender and blind to their serological status, was chosen for this study.

2.3.3 GPS Data

Individuals who consented to take part in this study were asked to wear GPS loggers for continuous periods of up to 48 hours, which could be repeated. The GPS loggers used were i-got U GT-600, set to record their location every 35 seconds. We used the manufacturer's software to programme the devices. Data were collected between March and November 2022.

Once the GPS telemetry data was collected, participants' recorded locations were cleaned so as to retain only relocations within the study area boundaries that were recorded between 5 am and 9 pm. This period generally corresponds to an individual's active hours. Interactions with environmental factors outside of the study area boundaries could not be considered in the analysis because high-resolution environmental data outside of the study areas was not available. Individuals with less than 50 relocations within the study area were excluded from the analysis to ensure good model convergence. Details of these excluded individuals can be found in Supplementary Material I.

2.3.4 Environmental Data

This analysis focused on three environmental factors: community stream, open sewers and domestic rubbish piles. The latter factor represented areas where rats were more likely to be found, whilst the other factors represented risks of having close contact with *Leptospira* contaminated muds or waters. The location of these different points of interest in the study area were mapped by trained research teams.

These environmental factors were included in analyses in two ways: using distance rasters and buffer rasters. A 1-meter resolution raster was created for each environmental factor by calculating the nearest distance for each pixel to the reference points. The buffer rasters, one for each factor, were created using a 20-meter buffer around each reference point. The size of this buffer was decided after visiting the study areas and represented an area within which it could be considered a strong interaction with the point of interest. All pixels within this buffer were assigned a value of 1, whilst those outside were given a value of 0. Buffers were used to understand the effect of the immediate vicinity of each reference point on movement behaviours. Buffer rasters were also created for each individual's household location, with a 10-meter buffer around each location. This represented space within and immediately outside each house. This buffer size accounted for the size of dwellings in these study areas.

2.3.5 Movement Analysis

The analysis was performed in two phases (Figure 2.2). Firstly, each individual's data was analysed alongside the environmental factors. This phase created a set of parameters—called selection coefficients—for each individual. These selection coefficients were specific to each of the environmental factors. In the second phase, the selection coefficient for a particular environmental factor was analysed across the study population. This phase incorporated the individual characteristics for each participant: gender, age and *Leptospira* serological status. These phases are detailed below. All analyses were carried out in R, version 4.2.1,[38] using tools from tidyverse.[39] Specific movement analyses were carried out using package amt.[40]

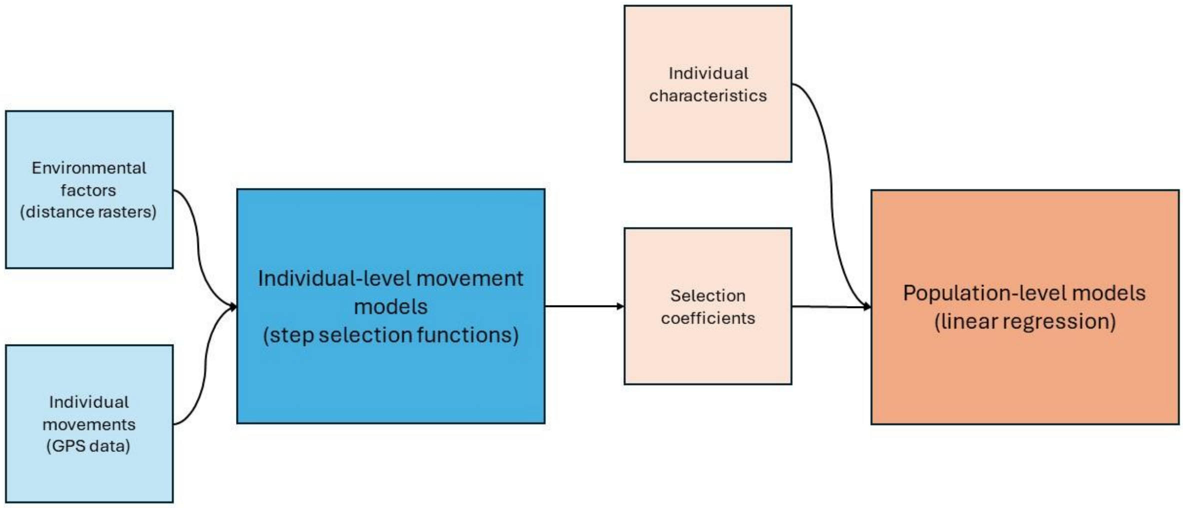


Figure 2.2 Schematic diagram showing what data sources are used in which model, and how models are linked with each other. The blue sections represent phase one, the individual-level models, whilst the orange section represent phase two, the population-level model

2.3.5.1 Phase 1: Individual-level model

Drawing from the current methodological developments in animal movement ecology, we used step-selection functions to characterise individuals' movement behaviours in relation to the environmental factors described above. Step-selection functions are a type of movement analysis method that fall under the Resource Selection umbrella. They can also be classified as spatio-temporal point process models.[26] In these models, an individual's location at time point i (μ_i) is conditioned on the previous location it was in (μ_{i-1}), the selection coefficients of the environment (β) and the available space the individual could have travelled to (θ).

$$[\mu_i|\mu_{i-1}, \beta, \theta] \equiv \frac{g(x(\mu_i), \beta) f(\mu_i|\mu_{i-1}, \Delta_i, \theta)}{\int g(x(\mu), \beta) f(\mu|\mu_{i-1}, \Delta_i, \theta)\, d\mu}$$

Step-selection functions have two important components: the availability function ($f(\dots)$) and the selection function ($g(\dots)$). The availability function defines the available space that an individual could move inside of within a set of space and time constraints. The selection function specifies how the individual responds to the environmental factors that are close to them when choosing their path, creating a set of selection coefficients for each factor—or resource–included in the model. These selection coefficients are specific to a given individual. This latter component is the focus of our analysis, whilst the former availability function was pre-defined using the empirical data.

The availability function was fitted separately to each recorded location. The step lengths and turning angles between consecutive steps were used to parametrise movement characteristics for an individual (Figure 2.3 A). Using these characteristics, a group of available steps (Figure 3B, grey dots) was created for each used step (Figure 2.3 B, black dots). These represented locations that were consistent with human movements that an individual could have travelled to but chose not to. A total of 100 available steps were created for each used step (Figure 2.3 B).

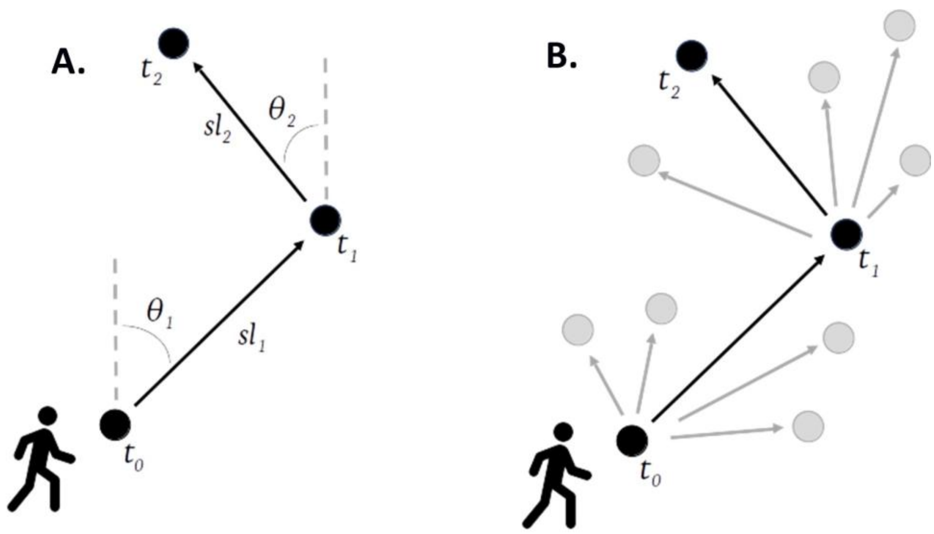


Figure 2.3 Descriptive diagram of step-selection functions. A: step lengths (sl) and turning angles (θ) are used to characterise an individual's movements. B: these parameters are used to create a set of available steps (grey dots) for every used step (black dots)

Each individual's telemetry data was analysed by time periods within daytime active hours. These were periods of 4 hours, representing morning (05:00 – 09:00), midday

(09:00 – 13:00), afternoon (13:00 – 17:00) and evening (17:00 – 21:00) activities. Movements across the whole daytime period were also analysed (05:00 – 21:00). This analysis was performed to examine the effects of circular journeys, when people travel to and back from a same place using a very similar route. By looking at specific time periods, we hoped to capture one-way journeys. As with the full day analysis, any individuals with less than 50 relocations within the period of analysis were removed from the models.

A conditional logistic regression was used to estimate the selection coefficients for each of the environmental variables for a given individual. A separate model was used for each time period.

$$logit(p) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 \beta_6 x_6 + \beta_7 x_7 + \beta_8 x_8 + \alpha_{stratum_j}$$

The model estimated the odds of a step being used compared to it being available and unused (p), with a logit transformation ($logit(p)$). The first three variables included in the model ($x_1 - x_3$) represented the different environmental factors (central stream, open sewers and domestic rubbish piles) and their corresponding selection coefficients ($\beta_1 - \beta_3$). Distance rasters and buffer rasters were included in separate models. The household buffer rasters were included in the next variable (x_4). The following three variables ($x_5 - x_7$) represent the movement characteristics of the individual: the step length (sl), the natural logarithm of the step lengths ($log(sl)$) and the cosine of the turning angle ($cos(\theta)$). These are the same movement characteristics used to create the set of available steps. The final variable included (x_8) was the hour within which each step was recorded. The model was stratified by each used step ($\alpha_{stratum_i}$), where j represents each used step and its associated available steps. This model estimates a selection coefficient for each of the environmental factors of interest, conditioned on all other environmental factors, the individual's household location, the individual's movement characteristics and the hour of the day. These selection coefficients can be interpreted as the likelihood of moving into a specific environmental condition whilst keeping other environmental factors, movement characteristics and hour of the day constant. For distance rasters, the selection coefficient represents odds of moving further away from the reference point. For buffer rasters, it represents the odds of moving inside of the 20-meter buffer of each reference point.

2.3.5.2 Phase 2: Population level model

To assess movement differences between individual characteristics, a population-level linear regression model was used. Separate models were created for each of the three environmental factors, using their corresponding selection coefficients as the outcome, and for each time period (whole daytime period, morning, midday, afternoon and evening). We used two main group of models: (1) those assessing differences between genders and ages, which were conditioned on both of these variables and the study area; (2) those assessing differences between *Leptospira* antibody statuses, which were conditioned on gender, age and study area. The shared equation for each of the models is defined as follows:

$$\hat{\beta}_k = \gamma_0 + \gamma_1 x_1 + \gamma_2 x_2 + \gamma_3 x_3 + \gamma_4 x_4 + Z_k$$

In these models, the outcome was the estimated selection coefficient ($\hat{\beta}$) for each environmental factor (k). The first two variables, x_1 and x_2, represented gender (taking values 0 for male and 1 for female), and age, used as a continuous variable. The third variable, x_3, represented *Leptospira* antibody status, as a binary variable taking values 1 for a positive test and 0 otherwise. As mentioned previously, a positive result was defined as a positive MAT result for any *Leptospira* serovar. The final variable in the model, x_4, represented the study area, included to adjust for any unmeasured differences between study areas. The error term, Z_k, captured the residuals from the model, which also accounted for any variation between individuals which was not measured as well as the sampling error inherent to the estimates of the selection coefficients. To account for variation in the standard errors of the selection coefficients, the variance of Z_k was defined as w_k/τ^2, where w_k is the estimated variance of $\hat{\beta}_k$ which was used to account for the heterogeneity in the estimate of $\hat{\beta}_k$.

2.4 Results

2.4.1 Descriptive statistics

There were a total of 130 individuals who consented to take part in this movement study. Of these, 2 individuals were removed from further analysis due to not having sufficient re-locations within the study area boundaries during the 5 am to 9 pm period. They were both male, older than 50 and tested negative for leptospirosis serology. The remaining 128 individuals represented 11.7% of the sample population from the parent study (n = 1086). Of the participants in the movement study, 59 (46.0%) were female and their ages ranged from 18 to 83, with a median age of 38 and mean age of 39.5 (SD = 15.5). There were 13 individuals (10.2%) who tested positive for *Leptospira* antibodies. Although these proportions were very similar to those present in the larger sample population from the parent study, the individuals in the movement analysis skewed female and older (Table 2.1).

Table 2.1 Summary table comparing parent study participants and movement study participants.

	Parent study participants		**Movement study participants**	
	n = 1086	*% / mean*	*n = 128*	*% / mean*
Study area				
1 – Nova Sussuarana	297	27.3%	32	25.0%
2 – Arenoso	246	22.7%	28	21.9%
3 – Jardim Santo Inacio	278	25.6%	35	27.3%
4 – Calabetao	265	24.4%	33	25.7%
Gender				
Female	454	41.8%	59	46.1%
Male	632	58.2%	69	53.9%
Age (mean +/- SD)	32.2	+/- 19.7	39.4	+/- 15.4
***Leptospira* antibody status**				
Positive	94	8.7%	13	10.2%
Negative	992	91.3%	115	89.8%

The majority of individuals spent most of their recorded time during their active daytime hours within their study area boundaries. The percentage of recorded time spent within the study area boundaries ranged from 4% to 100%. The mean percentage was 80%, with a median of 91% and a standard deviation of 25%. Females spent less time within the boundaries than men (females: mean = 76%, SD = 28%; males: mean = 83%, SD = 22%). Individuals who had antibodies against *Leptospira* spent the same time within the study area boundaries as individuals with no antibodies (positive: mean = 83%, SD = 26%; negative: mean = 80%, SD = 25%).

The maximum values for the different environmental distance rasters varied across the four study areas. The maximum distance to open sewers was lowest in study area 3 and highest in study area 2 (1: 199 m; 2: 235m; 3: 80 m; 4: 208 m). Similarly, the maximum distance to domestic rubbish piles was lowest in study area 3 and highest in study area 2 (1: 214 m; 2: 363 m; 3: 153 m; 4: 247 m). These differences are attributed to the number of open sewer points and domestic rubbish piles within each study area. The maximum distance to the central stream was highest in study area 1 and lowest in study area 3 (1: 217 m; 2: 209 m; 3: 94 m; 4: 172 m).

Similarly, the proportion of tracked time spent within the various environmental buffers varied across characteristics. These can be found in Table 2.2. There were significant differences between characteristics and within characteristics, represented by the high standard deviations. More detailed descriptive statistics are available in Supplementary Material I.

Table 2.2 Proportion of tracked time (full day period, 9 am to 5 pm) spent within each buffer. Mean (Standard Deviation)

		River buffer	Open sewer buffer	Domestic rubbish buffer
Total		0.54 (0.33)	0.33 (0.31)	0.07 (0.15)
Area	1 - Nova Sussuarana	0.54 (0.29)	0.43 (0.29)	0.15 (0.18)
	2 - Arenoso	0.65 (0.25)	0.28 (0.29)	0.03 (0.13)
	3 - Jardim Santo Inacio	0.36 (0.35)	0.41 (0.31)	0.08 (0.18)
	4 - Calabetao	0.67 (0.31)	0.21 (0.28)	0.01 (0.02)
Gender	Female	0.56 (0.32)	0.37 (0.32)	0.07 (0.15)
	Male	0.53 (0.34)	0.30 (0.29)	0.06 (0.16)
Leptospirosis serological status	Negative	0.55 (0.33)	0.35 (0.31)	0.07 (0.16)
	Positive	0.48 (0.29)	0.25 (0.30)	0.02 (0.05)

2.4.2 Movement analysis

The results from the movement analysis are presented in the odds scale. A positive value represents higher odds of moving towards an increasing value for each raster. As described previously, for distance rasters this is interpreted as moving further away from the point of reference (Table 2.3), whilst for buffer rasters this is interpreted as moving into the 20 meter buffer area for each point of reference (Table 2.4).

Table 2.3 - Estimated differences (γ) in selection coefficients (β) for each environmental factor using distance-based rasters. Values >1 represent increasing distance from points of reference.

	Community Stream		**Open Sewers**		**Domestic Rubbish Piles**	
	Estimate	*95% CI*	*Estimate*	*95% CI*	*Estimate*	*95% CI*
Gender *						
Male	(Ref)	-	(Ref)	-	(Ref)	-
Female	0.98	0.97, 0.99	1.04	1.02, 1.06	0.99	0.98, 1.01
Age **						
Per year increase	1.00	1.00, 1.00	1.00	1.00, 1.00	1.00	1.00, 1.00
Leptospira serological status ‡						
Negative	(Ref)	-	(Ref)	-	(Ref)	-
Positive	0.99	0.96, 1.01	1.03	1.00, 1.07	1.00	0.98, 1.02

* Adjusted for age and study area
** Adjusted for gender and study area. Values represent increases by one year of age
‡ Adjusted for gender, age and study area

We found no differences in how individuals moved in regards to the distance to the central stream by age (OR: 1.00; 95% CI: 1.00, 1.00; p = 0.697) or *Leptospira* antibody status (OR: 0.99; 95% CI: 0.96, 1.01; p = 0.273). Similarly, movements relative to the 20-meter buffer for the central stream were the same across ages (OR: 1.00; 95% CI: 1.00, 1.01; p = 0.280) and across *Leptospira* serological status (OR: 0.89; 95% CI: 0.67, 1.19; p = 0.433). There was evidence that women moved closer to the stream than men, even after accounting for the effects of age, study area and the location of their households (OR: 0.98; 95% CI: 0.97, 0.99; p = 0.003). This effect was more pronounced in the analysis of the 20-meter buffered area (OR: 1.22, 95% CI: 1.02, 1.46; p = 0.026).

As with the above, there was no evidence of different movement behaviours relative to distance to open sewers by age (OR 1.00; 95% CI: 1.00, 1.00; p = 0.572) or *Leptospira* antibody status (OR: 1.03; 95% CI: 1.00, 1.07; p = 0.054). Women were found to move further away from open sewers compared to men (OR 1.04; 95% CI: 1.02, 1.06; p < 0.001). When analysing movements relative to the 20-meter buffer around open sewers, we found no evidence of differences between genders (OR: 0.95; 0.80, 1.14; p = 0.580). We found evidence of a small tendency to move outside of the 20-meter buffer around open sewers as people aged, although the effect could be considered negligible (OR: 0.99; 95% CI: 0.98, 1.00; p = 0.003). We also found evidence of a strong inclination for people with *Leptospira* antibodies to move outside of the buffers around open sewers, compared to people with no antibodies (OR: 0.64; 95% CI: 0.47, 0.87; p = 0.005).

Table 2.4 - Estimated differences (γ) in selection coefficients (β) for each environmental factor using 20 meter buffers around each point of reference. Values >1 represent movement within the buffer zone for each point of reference.

	Community Stream		**Open Sewers**		**Domestic Rubbish Piles**	
	Estimate	*95% CI*	*Estimate*	*95% CI*	*Estimate*	*95% CI*
Gender *						
Male	(Ref)	-	(Ref)	-	(Ref)	-
Female	1.22	1.02, 1.46	0.95	0.80, 1.14	0.92	0.66, 1.27
Age **						
Per year increase	1.00	1.00, 1.00	0.99	0.98, 1.00	1.00	0.99, 1.01
Leptospira serological status ‡						
Negative	(Ref)	-	(Ref)	-	(Ref)	-
Positive	0.89	0.67, 1.19	0.64	0.47, 0.87	0.85	0.48, 1.49

* Adjusted for age and study area
** Adjusted for gender and study area. Values represent increases by one year of age
‡ Adjusted for gender, age and study area

Our analysis showed no evidence of different movement behaviours relative to the distance to rubbish piles across genders (OR: 0.99; 95% CI: 0.98, 1.01; p = 0.280), ages (OR: 1.00; 95% CI: 1.00, 1.00; p = 0.466) or *Leptospira* antibody statuses (OR: 1.00; 95% CI: 0.98, 1.02; p = 0.760). We also found no evidence when analysing movements relative to the 20 meter buffer around rubbish piles across genders (OR: 0.92; 95% CI: 0.66, 1.27; p = 0.600), ages (OR: 1.00; 95% CI: 0.99, 1.01; p = 0.989) or *Leptospira* antibody statuses (OR: 0.80; 95% CI: 0.44, 1.49; p = 0.482).

It is important to highlight that the effect sizes of the selection coefficients for the distance-based rasters (Table 3) are very small and could be considered negligible. This may be linked to the spatial scale used, as these values represent increases of 1 meter. A coarser scale may have produced larger effect sizes that may have been easier to conceptualise. However, given the focus on fine-scale movement, we decided to keep this spatial scale for the analysis.

2.4.2.1 Analysis by time periods

Movements were subdivided into four time periods: morning (5 am -- 9 am), midday (9 am -- 1 pm), afternoon (1 pm -- 5 pm) and evening (5 pm -- 9 pm). The demographic characteristics of all individuals removed from analyses for having less than 50 relocations within a specific time period can be found in Supplementary Material I. The interactions with the environmental factors were similar to those reported for whole day activities, although there were some key differences (Figure 4).

We found no differences in movements relative to the central stream as people aged or between *Leptospira* antibody status across the four periods. Women still moved closer to the central stream than men across all periods. We also saw that women had a higher tendency to move within the 20-meter buffer for the stream compared to men across all periods.

Movement in relation to distance to open sewer points and their respective 20-meter buffers showed no difference across all four periods. The strength of the selection effect seen in serological positive individuals for moving outside of the 20-meter buffer varied, with stronger effects seen in the morning and evening periods.

Domestic rubbish piles did not appear to have an effect on movement differences between ages or *Leptospira* antibody status across all periods. We found women moved outside of the 20-meter buffer zone more than men during the morning period only. Otherwise, no notable differences were seen.

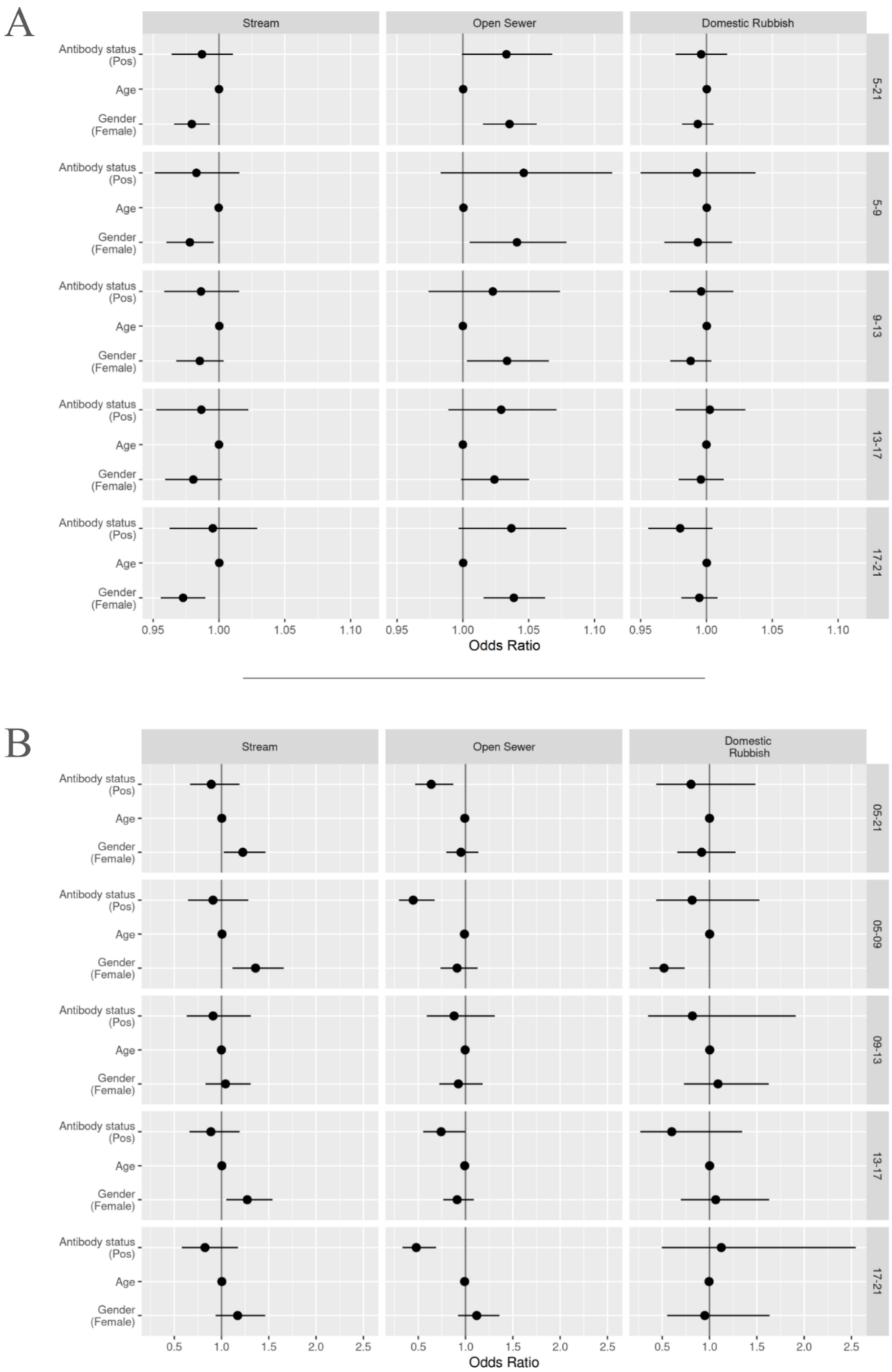


Figure 2.4 Graph showing results of final analyses: A) results for distance based rasters, values above 1 interpreted as increasing distance to points of reference; B) results for 20 meter buffer based rasters, values above 1 show movement within buffer zones. Each horizontal band represents a specific time period (right hand side y-axis label): all day (5 am – 9 pm, Tables 2 and 3), morning (5 am – 9 am), midday (9 am – 1 pm), afternoon (1pm – 5 pm) and evening (5 pm – 9 pm). All data points include their corresponding 95% confidence intervals, some of which are too narrow to show up clearly.

2.5 Discussion

Our study aimed to apply a novel methodology to the area of human mobility analysis in infectious disease epidemiology, focusing on leptospirosis in four urban slums in Salvador, Brazil. We assessed movements in relation to central streams, open sewer points, and domestic rubbish piles and observed changes throughout the day using step-selection functions. These are a modelling approach which we have taken and adapted from animal movement ecology. Our findings showed that step selection functions could be an effective method to identify movement behaviours. To understand how the results could be described in the context of infectious disease epidemiology, we have explained our interpretation of the findings, including strengths and limitations. However, it is important to highlight that, given this is a novel methodology, the evidence we present is not conclusive and further research is required.

The results suggested no movement differences between *Leptospira* antibody statuses or ages concerning the distances to stream, open sewer points, or domestic rubbish piles. Our findings consistently showed that women tended to move closer to the central stream and farther from open sewer points than men, adjusted for age and study area. We also found that women had a tendency to move within the 20-meter buffer of the central streams compared to men, and that seropositive individuals were more inclined to move outside of the buffer zone for open sewers compared to seronegative individuals. Movement patterns did not vary significantly throughout the day. Previous research indicates that men in similar communities perceive themselves as less vulnerable to leptospirosis compared to women.[41] Additionally, a knowledge, attitudes and practices analysis showed that men have lower scores for both knowledge and attitudes towards leptospirosis and its associated risks.[18] Our findings align with these studies, suggesting that women may avoid open sewers due to perceived risks, while men may not share these perceptions. Social areas, which may have gender differences, also contribute to different movement behaviours. One might conclude that the stream is used for gendered chores such as washing clothes. However, this is not the case in our study areas. Following discussion with residents, we know that they perceive the stream as highly contaminated and avoid using its waters for cleaning or other household chores.

Our results contrast those reported by Owers et al, 2018.[32], who found no differences in space use between genders after using GPS loggers to analyse individuals' movements. This discrepancy could be explained by the differences in length of time being analysed. Owers et al., 2018, were only able to analyse data collected over 24-hour periods, whereas our analysis was longer and included data collected over periods of up to 48 hours, which could be repeated. The contrasting results could also be attributed to the different populations studied. Although overall these populations resided in very similar communities in Salvador, they could have different characteristics that affect movement behaviours.

Our findings regarding the interactions with rubbish piles may be explained by various reasons. There is evidence that proximity to rubbish piles does not drive *Leptospira* seropositivity in similar areas to those used in our analysis.[41] Whilst this proximity does increase rat sightings, this reduced effect on infection risk could lead individuals to disregard the locations of rubbish piles when choosing their travel paths. Another possible explanation is that there may be an unmeasured environmental variable that is interacting with the distance to rubbish piles, which needs further investigation. For example, violence could be interacting with where rubbish accumulates. We discuss violence further in a paragraph below.

The evidence showing *Leptospira* positive individuals avoiding open sewers was surprising. Although we were expecting to see an effect in the opposite direction, showing individuals with *Leptospira* antibodies interacting closely with open sewers, there are a few possible explanations for our findings. If individuals with antibodies are also actively infected, they could be symptomatic and therefore alter their behaviour to avoid high risk areas. Alternatively, individuals with antibodies could be more aware of risks due to previous infections and display more protective behaviours than people who have not had any previous infections.

During informal conversations with community residents, it became clear that violence plays a key role in individual's decisions on where they go. Violence in these communities is perceived as hyper-local, restricted to one corner or small square within the communities. It is unclear what drives this perception, but nevertheless it is an important factor that could be accounted for. Further research is required to develop methods that can capture these perceptions in spatial formats that could be incorporated into similar movement studies. Age did not affect movement choices, suggesting consistent perceptions of environmental risks or stable use of urban spaces across ages.

We expected different movement patterns at various times of day, anticipating circular journeys (an individual going somewhere and back again on the same route). However, our results showed consistent movement patterns, possibly due to the analysis period's length or other unmeasured factors modulating movements. Our results could also be indicative of evidence that strictly circular journeys through these communities, where individuals are travelling through the exact same path for both journeys, are not common, and that movement interactions with urban surroundings do not vary throughout the day.

To our knowledge, this is the first study that uses step-selection functions to model movement behaviours in the context of human infectious disease epidemiology. This method has provided quantitative evidence that there may be differences in how men and women move through their communities, strengthening the argument that the variation in leptospirosis exposure and infection risk between genders is due to behavioural differences rather than physiological differences. Additionally, we show that individuals consider environmental features differently when moving through their communities. Highlighting the effects of these variables on movement would not have been possible with the approaches previously used to model human movement. Our approach provides a better understanding of how individuals relate to their surrounding urban environment and how they interact with features that could increase risk of leptospirosis.

Several important limitations must be highlighted. This study involves a relatively small sample of a larger population, slightly skewed towards older women compared to the parent study. There are few individuals testing positive for *Leptospira* antibodies. As a result, the findings are biased towards the more represented individuals, limiting their generalisability. Additionally, all participants are from specific areas in Salvador, which may further limit the generalisability to similar contexts. Further research is needed to develop appropriate study designs using these methods, including how many individuals should be recruited. The small number of *Leptospira*-positive individuals also makes the estimation for the effect of this characteristic more difficult. We would also like to restate that a positive antibody response to any *Leptospira* serovar does not indicate active infection. A positive result merely indicates that the individual has been infected at some stage, either symptomatically or asymptomatically, and has produced an immune response. Information on the timing of the infection could instead be a variable showing a stronger association with movement. Another important limitation is that we did not collect data on behaviours. If risky or protective behaviours, such as the use of closed footwear, had been available at the appropriate temporal resolution (e.g. hourly intervals), these could have been included in the step selection functions and could have shown significant associations. Although these are important limitations which require cautious interpretation of results, they do not detract from the value of exploring this novel methodology in this context. This methodology also provides a crucial starting point for exploring how movement characteristics can differ between individuals in these environments.

Step-selection functions also have limitations that must be considered. While these methods can model the choice of moving in a specific direction, they do not account for the initial distance from the individual. For instance, an individual moving towards the central stream from far away will have a high selection coefficient for this environmental factor, which does not indicate their starting distance. This is important because environmental risk factors cease to provide risk beyond a certain distance. This limitation was overcome by using buffer zones around specific points of interest, but it is crucial to highlight to correctly interpret all results. Similarly, step-selection functions do not quantify how long an individual spent within this high-risk distance. Additionally, these models have some underlying assumptions that may be violated in this study. Step-selection functions assume each step is independent, conditioned on the previous step. This can be violated by circular journeys. Although we attempted to account for these by analysing specific periods of the day, a higher temporal resolution of analysis may be needed if circular journeys are still present within each period. Another assumption is that movement is smooth through the environment. In urban environments this may not hold true, as street layouts may force sharp corners in movements. The effect of violating this assumption is not immediately clear and requires further methodological research to understand its significance. Finally, we assumed that by including movement characteristics (step lengths and turning angles) into our models, we were accounting for goal-oriented behaviour. These assumptions need to be considered in future studies that attempt to use step-selection functions to analyse human mobility.

Despite these limitations, this study has several valuable strengths. By including steps an individual could have taken but did not (i.e., available steps, grey dots in Figure 3B), the models allow us to estimate choice. Additionally, the models use each individual's movement characteristics to create these available steps, resulting in a realistic representation of movement behaviours. This creates more realistic estimates of environmental interactions than those created using existing methods.

Another significant strength is the specificity of the individual-level and population-level models. First, the population-level linear regression models allow multiple individual characteristics to be included, producing results that can be adjusted as needed. Although not considered in this study, these models also provide flexibility in the type of variable interactions that can be specified, allowing for non-linear effects if necessary. Second, the individual-level conditional logistic regression models are conditioned for all included variables. This enables the estimation of the selection coefficients for each environmental factor after adjusting for potential confounders. This is particularly useful in our case, as open sewer points are often close to the central stream in all study areas (Figure 2.1).

Overall, we believe this method is a useful tool in analysing human mobility in the context of infectious disease epidemiology. This modelling approach could also be used in other areas of research which analyse human movements and choice relating to surrounding environmental features, such as urban planning. A major benefit of step selection functions is the use of rasters, which provide flexibility when investigating environmental features. Creative uses of rasters could provide interesting questions and results. Although the focus of these models is looking at choice in space, the methods could also be adapted to analyse choice in time (e.g. are there temporal variables that affect when a rat enters a household).

To conclude, we provide a worked example of how to use step-selection functions to analyse human movements in the field of infectious disease epidemiology. This highlights the usefulness of adapting methods from other fields to answer questions that would otherwise be difficult to answer with the existing methodology. By doing so, we develop a better understanding of environmental interactions and how to leverage the large data sets provided by GPS loggers. Although our focus was leptospirosis, these methods can be adapted to model the exposure to any disease where movement and the environment play an important role.

2.6 Ethics

Ethical approval for this study was obtained from the ethics committee at the Collective Health Institute, Federal University of Bahia (CEP/ISC/UFBA) under number CAEE 32361820.7.0000.5030, and the national research ethics committee (CONEP) linked to the Brazilian Ministry of Health under approval number 4.235.251. All participants involved in the study provided written informed consent before data collection.

2.7 Acknowledgments

We would like to thank all residents from the study areas, without whom this work would not have been able to be completed. The authors would also like to specially thank the GIC (Grupo Impulsor Comunitario) for their support and warmth.

2.8 Supplementary Material I

2.8.1 Descriptive Statistics

2.8.1.1 Telemetry data

The mean number of hours of telemetry data provided by an individual was 13.3 hours, with a standard deviation of 13.5 hours. The mean number of locations recorded by the GPS loggers was 2767 points (SD = 1947.2). There were no differences in the number of hours or number of locations recorded by gender, age or leptospirosis antibody status. There were notable differences in the number of hours recorded and the number of locations by study area. Study area 1 (NVS) had the lowest number of hours recorded (mean = 5.6 hours, SD = 5.6), whilst all other areas had similar hours recorded (area 2: mean = 15.0, SD = 11.4; area 3: mean = 10.9, SD = 14.0; area 4; mean = 20.7, SD = 15.3). The mean number of locations recorded were all similar across all study areas (area 1: mean = 2048, SD = 1206; area 2: mean = 2831, SD = 1302; area 3: mean = 2992, SD = 2737; area 4: mean = 3107, SD = 1761).

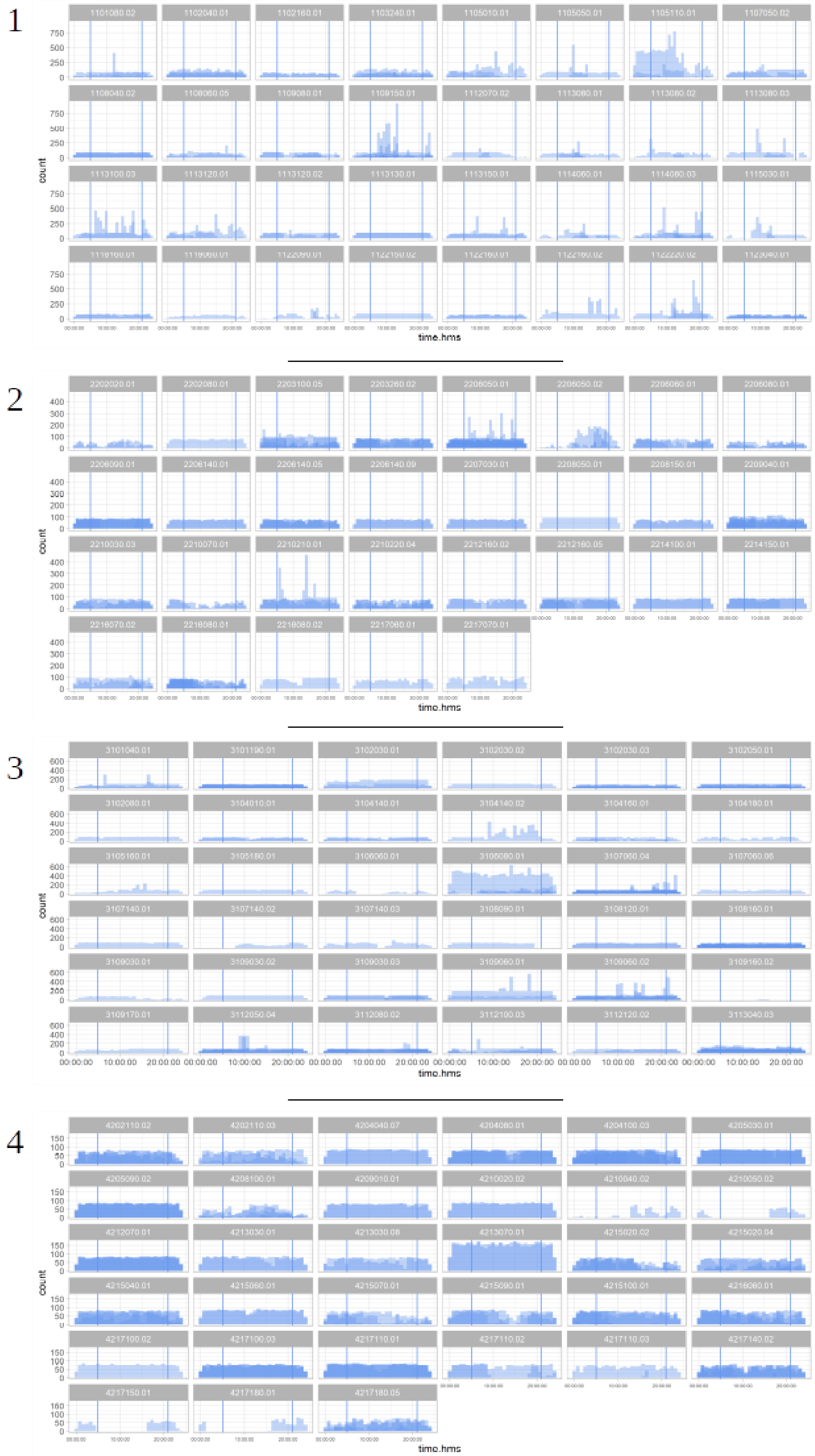


Figure 2.5 Distribution of telemetry data provided by each individual across 24 hour periods (x axis), separated into each of the four study areas (1 : NVS, 2 : ARE, 3 : JSI, 4 : CAL). Overlapping areas represent multiple days. Vertical bars represent 5 am (left hand bar) and 9 pm (right hand bar), the period of analysis

2.8.1.2 Excluded individuals

Table 2.5 Demographic details of excluded individuals due to having less than 50 relocations

ID (anonymised)	Relocation below 50	Period	Gender	Age group	Leptospirosis serological status
60	TRUE	05-21	Male	50-54	Neg
91	TRUE	05-21	Male	>55	Neg
15	TRUE	05-09	Female	45-49	Neg
60	TRUE	05-09	Male	50-54	Neg
81	TRUE	05-09	Female	50-54	Neg
91	TRUE	05-09	Male	>55	Neg
108	TRUE	05-09	Female	50-54	Neg
109	TRUE	05-09	Male	20-24	Neg
128	TRUE	05-09	Male	25-29	Neg
129	TRUE	05-09	Male	40-44	Pos
15	TRUE	09-13	Female	45-49	Neg
24	TRUE	09-13	Female	50-54	Neg
60	TRUE	09-13	Male	50-54	Neg
70	TRUE	09-13	Male	35-39	Neg
71	TRUE	09-13	Female	35-39	Neg
76	TRUE	09-13	Male	35-39	Neg
91	TRUE	09-13	Male	>55	Neg
108	TRUE	09-13	Female	50-54	Neg
109	TRUE	09-13	Male	20-24	Neg
128	TRUE	09-13	Male	25-29	Neg
129	TRUE	09-13	Male	40-44	Pos
24	TRUE	13-17	Female	50-54	Neg

60	TRUE	13-17	Male	50-54	Neg
71	TRUE	13-17	Female	35-39	Neg
76	TRUE	13-17	Male	35-39	Neg
91	TRUE	13-17	Male	>55	Neg
5	TRUE	17-21	Male	35-39	Neg
7	TRUE	17-21	Male	50-54	Neg
18	TRUE	17-21	Male	30-34	Neg
22	TRUE	17-21	Male	45-49	Neg
24	TRUE	17-21	Female	50-54	Neg
27	TRUE	17-21	Male	30-34	Neg
30	TRUE	17-21	Female	>55	Neg
60	TRUE	17-21	Male	50-54	Neg
71	TRUE	17-21	Female	35-39	Neg
91	TRUE	17-21	Male	>55	Neg
114	TRUE	17-21	Female	40-44	Neg

2.8.2 Serological data

Serologically positive individuals were equally distributed across ages and genders, although the oldest male included in the analysis was also serologically positive (Figure 2.6).

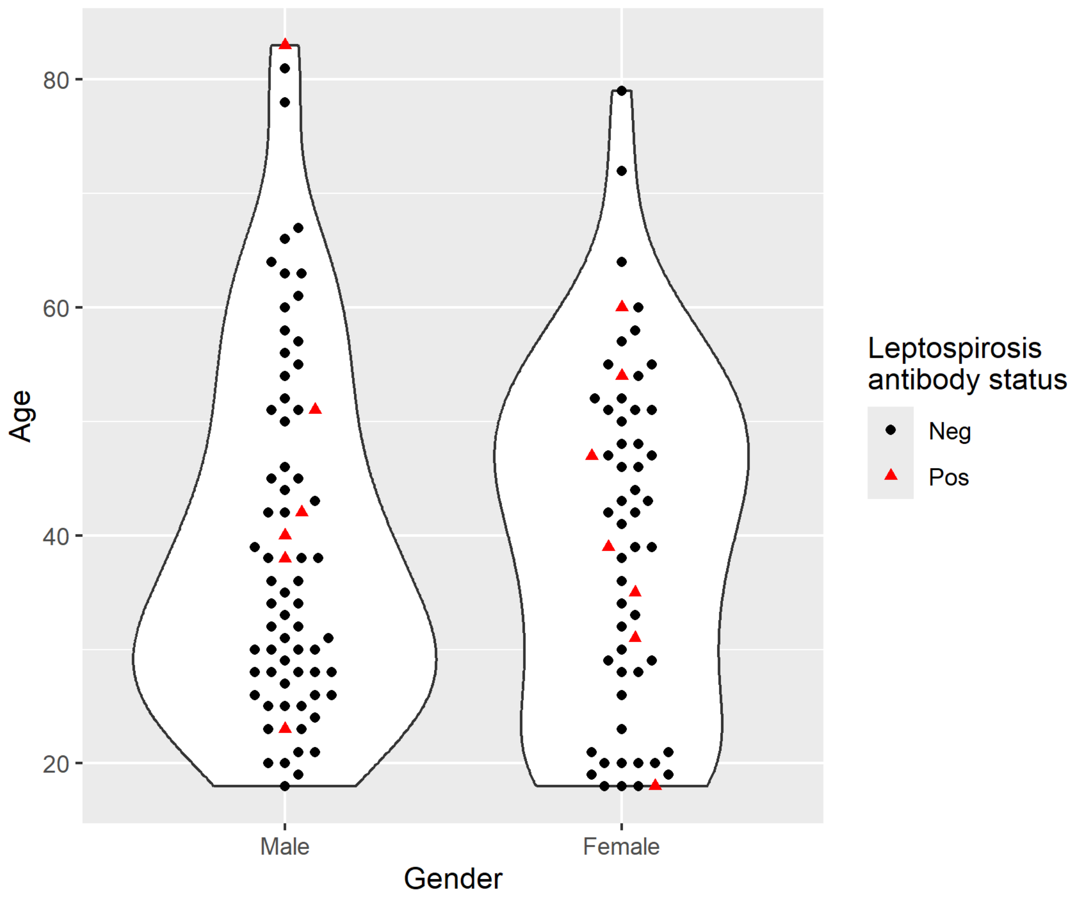


Figure 2.6 Distribution of Leptospirosis antibody status (serological status) by gender and age.

There were also no significant skews in the household characteristics relative to the environmental factors being analysed (Figure 2.7).

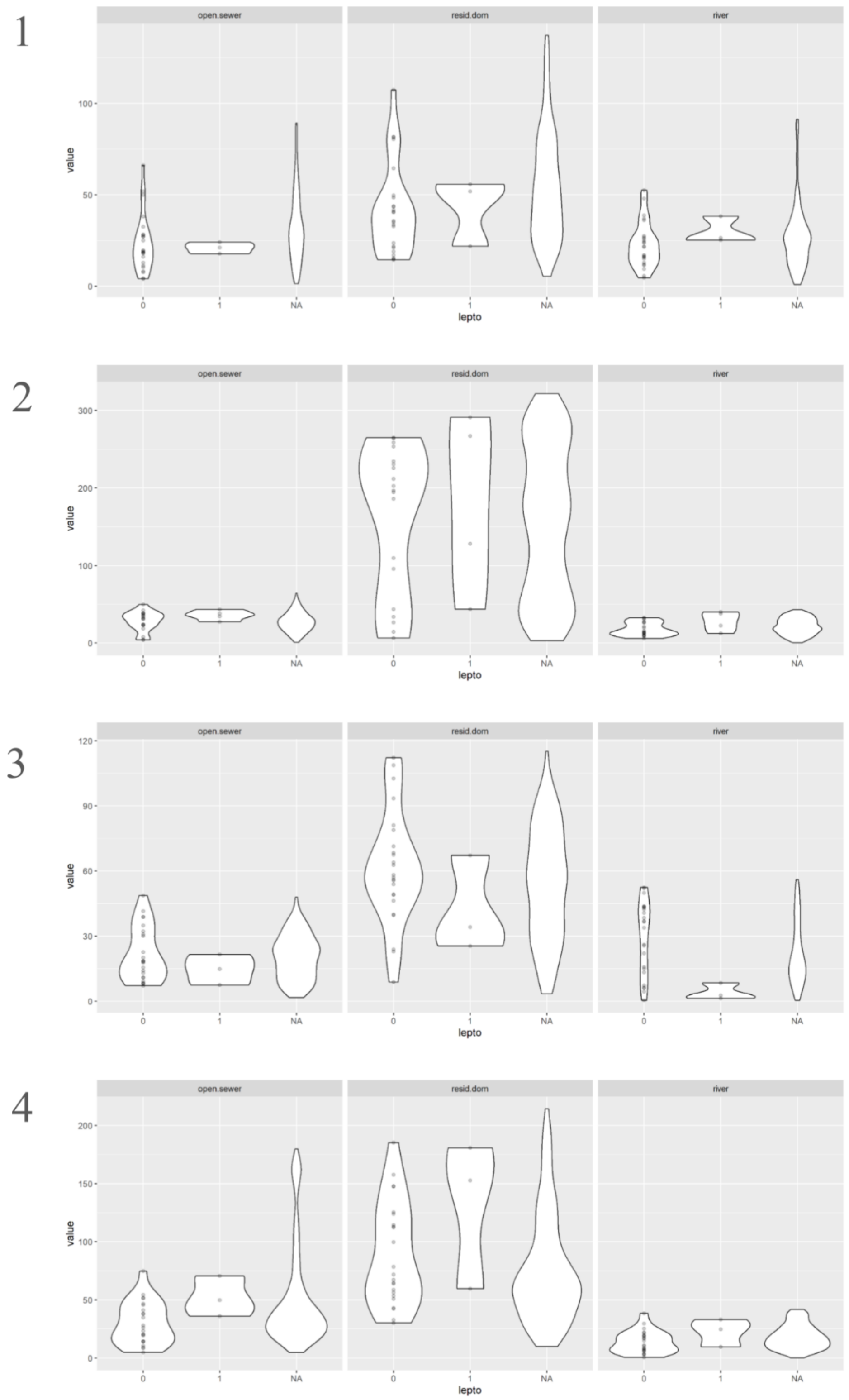


Figure 2.7 Distribution of nearest distance to each of the environmental factors being analysed (central stream, open sewer points and domestic rubbish piles) by serological status (x axis) and study area (1: NVS, 2: ARE, 3: JSI, 4: CAL). NA represents rest of households in study area that did not take part in movement analysis

2.8.3 Laboratory work

All samples were tested using the MAT test, the reference test for serological diagnosis of leptospirosis, as designated by the WHO. The diagnostic panel used included the following serovars:

- *L. kirschneri* serovar Cynopteri strain 3522C
- *L. kirschneri* serovar Grippothyphosa strain Duyster
- *L. interrogans* serovar Canicola strain H. Ultrech
- *L. interrogans* serovar Autumnlais strain Akiyami A
- *L. borgspetersenii* serovar Ballum strain MUS 127
- *L. interrogans* serovar Copenhageni strain Fiocruz L1-130 (locally isolated in 1996)
- *L. interrogans* serovar Copenhageni strain Fiocruz LV3954

Chapter 3 Estimating variability of human movement behaviours associated to leptospirosis environmental risk in urban tropical communities using GPS data

Pablo Ruiz Cuenca[1], Fabio Neves Souza[2,3], Roberta Coutinho do Nascimento[3], Ariane Gonçalves da Silva[2,3], Max T. Eyre[4], Juliet O. Santana[2,3], Priscilla Elizabeth Ferreira dos Santos[2], Saulo Pereira Passos[2], Maria Victoria Moraes Oliveira[2], Daiana Santos de Oliveira[2,3], Fabiana Almerinda G. Palma[2], Diogo César de Carvalho Santiago[2], Priscyla dos Santos Ribeiro[5,6], Jonathan M. Read[1], Cleber Cremonese[2], Hussein Khalil[7], Federico Costa*[2,3,8] and Emanuele Giorgi*[1]

1 Centre for Health Informatics, Computing, and Statistics (CHICAS), Lancaster Medical School, Lancaster University, United Kingdom

2 Institute of Collective Health, Federal University of Bahia, Salvador, Bahia, Brazil

3 Instituto Gonçalo Moniz, Fundação Oswaldo Cruz, Ministério da Saúde, Salvador, Bahia, Brazil

4 Environmental Health Group, London School of Hygiene and Tropical Medicine, London, United Kingdom

5 Federal University of Bahia, National Institute of Science and Technology in Interdisciplinary and Transdisciplinary Studies in Ecology and Evolution, Salvador, Brazil

6 Amsterdam University Medical Centre, Leptospirosis Reference Center, Medical Microbiology and Infection Control, Amsterdam, Netherlands

7 Department of Wildlife, Fish and Environmental Studies, Swedish University of Agricultural Sciences (SLU), Sweden

8 Department of Epidemiology of Microbial Diseases, School of Public Health, Yale University, New Haven, CT, United States

** These authors contributed equally to this work.*

3.1 Abstract

Leptospirosis is a leading cause of disease in urban tropical areas across the world. This zoonotic bacterial infection has strong environmental drivers, such as contact with contaminated soil. Previous research has used household-based models to analyse environmental risk, assuming individuals are most at risk in their homes. However, there is limited knowledge of how people may encounter environmental risks and interact with them as they move through their neighbourhoods. In this study, we used GPS loggers to investigate people's movement behaviours. In particular, we looked at how long they spent at home, how far they travelled, how much space they used and how they interacted with specific environmental risk factors in their daily routines. We found evidence that men were more likely to be at home and interact more closely with open sewers than women. During heavy rainfall days, participants travelled further from home, used more space and were less likely to be at home compared to no rainfall days. Leptospirosis seropositive participants travelled further and were more likely to be at home than seronegative individuals. Our research shows that there is significant variation in movement behaviours, which could be modulating infection risk for leptospirosis.

Keywords: human mobility, telemetry data, zoonosis, infectious disease epidemiology, urban health

3.2 Introduction

Leptospirosis is a zoonotic disease caused by infection with spirochaete bacteria from the genus *Leptospira*. It was traditionally seen as a rural disease, mostly affecting farmers in tropical regions. However, recent estimates of disease burden have shown that it is increasingly becoming an urban disease, affecting people living in informal or low-quality settlements. These estimates have attributed over 1 million yearly cases worldwide to leptospirosis, with approximately 60 thousand yearly deaths.[1] Although infectious bacteria can be shed by a wide range of mammals, the most common carrier in urban tropical settings is the rat.[35] Rats release bacteria in their urine, which contaminate waters and soils. Humans can become infected after coming into close contact with these contaminated sources. This results in strong environmental associations with human leptospirosis cases.[10,42,43] Although there is clear evidence that these associations exist, there is still uncertainty about where exactly most infections occur, with the most discussed possibilities being exposure within the domestic and peridomestic area or in the surrounding local community.[10] Rapid uncontrolled urbanisation in tropical regions, often with little official oversight, coupled with an increase in extreme weather events due to climate change are creating heightened risks for residents in these areas. There are also additional socioeconomic determinants of health modulating these risks, as the most affected neighbourhoods are often the poorest, receiving little attention from local governments.

Technological advancements in wearable devices, such as GPS loggers, have opened up the opportunity to research fine-scale human movements in an objective way. These devices record the coordinates of their location at set time intervals. When individuals wear them, they collect the movements throughout their regular daily activities. This data can be used to analyse how individuals move, how they use the space available and how they interact with their environment. Although other methods for analysing movements exist, such as Google location history or cell tower traffic, the biggest benefit of using GPS loggers is that their data can be assigned to a specific individual (the wearer).[20,32,33,44] This permits the data collected to be characterised by that individual, be it their socio-demographic features or, in the case of epidemiological studies, their disease status. Owers et al, 2018, took advantage of the benefits granted by GPS loggers to study how residents in a slum setting in Salvador, Brazil, moved throughout their daily schedule.[32] They calculated how many GPS points were logged in or near an individual's home and how many were in the local neighbourhood. They also estimated the wearers’ space use by calculating the total daily activity space, a method that quantifies the area an individual has used throughout their daily activities.[45] They found that men travelled further and had a higher activity space than women. They also found no evidence of any gender differences with regards to the time spent in or near their homes. Although they had data on leptospirosis disease status of participants, they were not able to draw any clear conclusions about movement differences due to the low number of positive individuals. This study was highly innovative in the field of infectious disease epidemiology and presented some compelling evidence on differences in movements and space use. However, it also had important limitations, such as the low number of participants, the short period of analysis and the difficulties in analysing environmental interactions.

In this paper, we present a research study that revisits some of the questions asked by Owers et al, 2018, in a similar context. We used GPS loggers on consenting residents of three urban settings in Salvador, Brazil, to understand how much time they spent within the domestic and peridomestic areas, how far they travelled from home, how much space they used and how they interacted with specific environmental factors. These questions are important to develop a better understanding of the movement behaviours of residents and how this may relate to the risk landscape for leptospirosis and other infectious diseases. In particular, how much time residents spend within their domestic environment compared to the community environment is important to try to decipher where exposure of the pathogen is more commonly occurring. We were able to recruit more participants and follow them for a longer period of time than the research presented by Owers et al, 2018. We also applied a novel movement analysis method, called integrated step selection functions, to understand how individuals interact with specific environmental factors.

3.3 Materials and Methods

3.3.1 Study areas

This study is nested within an ongoing prospective cohort study.[19] The parent study involves assessing an eco-social intervention in peripheral neighbourhoods in Salvador, the third largest city in Brazil. The intervention has two components: a structural component, which is focusing on improving the local sewage system in the study areas, and a social component, empowering residents to become health champions and encouraging them to link their household refuse pipes to the new and improved local sewage system. The intervention is targeted to the entire study area, which is matched to a control area with similar sociodemographic and ecological characteristics which receives no intervention. All study areas have a stream running through the centre of them.

In this research, we used data from three of the study areas (Figure 3.1): Nova Sussuarana (NVS, an intervention area), Arenoso (ARE, a control area) and Calabetao (CAL, a control area). We did not use the data from the intervention area that corresponded to CAL due to logistic delays. However, we decided to include the CAL data to improve the number of data points we had and the comparability between intervention and control groups.

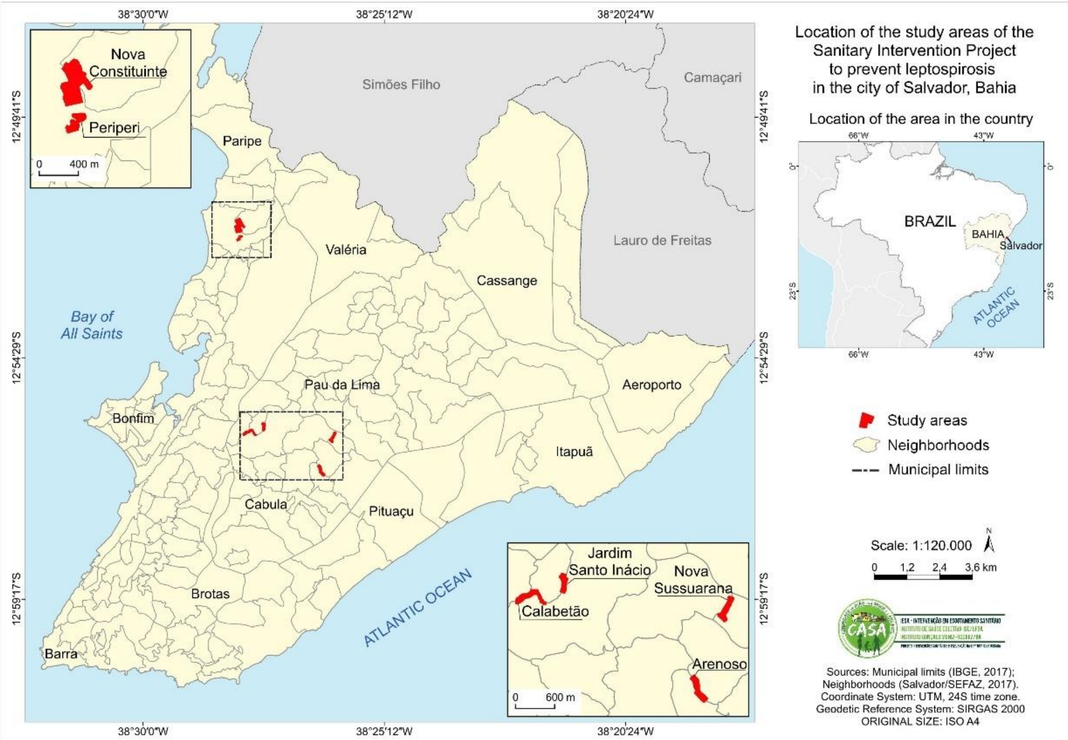


Figure 3.1 Map showing study areas of intervention study.[19] In this paper, we used data from three of these areas: Nova Sussuarana, Arenoso and Calabetao (lower right box)

For each of the study areas, we had two collection periods. The baseline period was run from 3rd March 2022 to 1st April 2022 for NVS, 19th July 2022 to 7th August 2022 for ARE and 21st October 2022 to 26th November 2022 for CAL. The first follow up period was collected from 6th October 2023 to 1st December 2023 for NVS, 8th March 2024 to 12th April 2024 for ARE and 16th July 2024 to 12th September 2024 for CAL.

3.3.2 Participants' data

Participants for the parent study were recruited from all study areas. Eligibility criteria for participating were: 1) having lived in a household within the study area boundaries for at least the previous 6 months, 2) sleeping at least 3 nights a week in that household, 3) being at least 18 years old, and 4) able to provide consent for participating. Participants were asked to answer a questionnaire about themselves, collecting demographic and socio-economic characteristics. The coordinates of their household were recorded.

They were then asked to provide a blood sample for serological testing which was collected by trained phlebotomists within the research group. The sample was tested to determine the leptospirosis seropositivity of each individual. This was carried out using the microscopic agglutination test (MAT), the gold standard serological test for leptospirosis diagnosis according to the WHO.[8] We considered a MAT showing over 50% agglutination of leptospires at a titre of > 1:50 against any *Leptospira* serovar from our panel to be a positive result. Our panel included the following serovars: *L. kirschneri* serovar Cynopteri strain 3522C, *L. kirschneri* serovar Grippothyphosa strain Duyster, *L. interrogans* serovar Canicola strain H. Ultrech, *L. interrogans* serovar Autumnlais strain Akiyami A, *L. borgspetersenii* serovar Ballum strain MUS 127, *L. interrogans* serovar Copenhageni strain Fiocruz L1-130 and *L. interrogans* serovar Copenhageni strain Fiocruz LV3954. These represented the most prevalent serovars in the region, as well as other known pathogenic serovars.

3.3.3 GPS data

We used the pool of participants in the parent study to recruit individuals for this research. Given there is limited methodological research looking at how to carry out a study size calculation for movement analysis using GPS data, we opted to use targeted recruiting of individuals, balanced by gender. In the baseline stage, we aimed for 30 individuals per study area. This number provided us the most effective use of our resources at that stage. Due to having significant losses to follow up, we carried out open recruitment during the follow up stage. We increased the target to 40 individuals per study area, prioritising the recruitment of the same individuals from the baseline stage.

We asked participants to wear the GPS devices, i-got U GT-600, for a set period of time. Two different protocols were used during the baseline and follow up stages. During the first collection period in the baseline stage, we asked participants to wear the devices for up to 48 hours. The devices were programmed to record coordinates every 35 seconds. These 48-hour intervals could be repeated for each individual. Following an initial analysis of this data, we decided to change the protocol to collect data which would be more representative of individuals' movements. For the second collection period in the follow up stage, participants wore the devices for up to 7 continuous days. Here the devices were set to record locations every 5 minutes.

This GPS data was separated into daily data sets for each individual. We used these to calculate the daily mean distance travelled from each individual's household, the daily activity space and the daily proportion of GPS points within the domestic and peridomestic area. Daily mean distances were calculated by estimating the distance between each GPS point and the individual's household, which were then used to calculate the mean distance travelled, in m, for each day. Daily activity space was calculated using the Daily Path Area (DPA) method proposed by Zenk et al, 2011, and implemented by Owers et al, 2018.[32,45] Each GPS point is assigned a buffer. These buffers are combined to calculate the total area an individual uses within a specific day. To be able to compare results, we used the same buffer size as Owers et al, 2018, which accounted for positional uncertainty of the GPS point. The daily proportion of GPS points within the domestic and peridomestic area were calculated by counting the number of points within a 10-meter buffer of each individual's household. This 10-meter buffer represented the domestic and peridomestic area, and the value was chosen following personal visits to the study areas to assess household size.

3.3.4 Environmental data

We used a group of different environmental data sets in our analyses. As part of one of our objectives, we were interested in understanding how individuals moved with regards to 3 specific environmental factors: open sewer points, domestic rubbish piles and each study area's central stream. These were chosen due to their direct or indirect associations with leptospirosis infection in humans. Open sewers are a known risk factor for leptospirosis infection.[10] Domestic rubbish piles are associated with more rat presence, which in turn is linked to leptospirosis infection.[46] Research has shown that areas in close proximity to contaminated streams are also contaminated with *Leptospira* bacteria, representing a high risk for infection.[47] All three factors were mapped by trained research staff, creating vector spatial data for each one. These vector data sets were used to create two types of rasters: a distance raster and a buffer raster. For the distance rasters, we used a 1-meter resolution grid over each study area and calculated the minimum distance to open sewers, rubbish piles or central streams for each pixel. For buffer rasters, we created a 20-meter circular buffer for each of the environmental factors. We again used a 1-meter resolution grid, assigning the value of 1 to any pixels inside the buffers and 0 otherwise.

We also used a topographic wetness index (TWI) raster in our analyses, created by Pedra as part of their PhD thesis.[48,49] TWI is a proxy for flooding risk with no units, calculated accounting for slope and urban layout. Higher values represent higher risk of flooding. The raster was available at a 5-meter resolution for the entire city of Salvador.

Rainfall was an important environmental component in our analyses. Research has shown that increased rainfall is associated with an increase in hospitalisations due to leptospirosis.[16] We used data collected by the National Center for Monitoring and Alerts for Natural Disasters (*Centro Nacional de Monitoramento e Alertas de Desastres Naturais*, CEMADEN) across Salvador, Brazil. Given the high spatial variability in climate across the city of Salvador, we identified the closest climate stations to each of our study areas on each day. This allowed us to create highly specific rainfall data for each area. We used this data to classify the daily rainfall into three categories: no rain, light rain and heavy rain. Light rain represented days with at least some rain which fell below the 75th percentile for each area. Heavy rain were days over the 75th percentile of rainfall for each area.

3.3.5 Models

We used different models to assess the different research questions, accounting for varying data structures. We used a weighted log-linear mixed effects model to analyse the differences in both daily mean distances and daily activity space. A mixed-effects model was used given the hierarchical nature of the data, using individual-level random effects. The model was weighted by the number of GPS points that each individual had for each given day. The log transformation was applied to account for the strong positive skew of both these variables (see Results). Therefore, the resulting estimates from these models are to be interpreted as multiplicative effects, rather than additive effects.

To decide which variables to include in each of the models, we initially examined the univariable associations of each of the outcomes with a group of factors. These included individual factors (gender, age, worker status, leptospirosis serological status), household factors (study area, household elevation, household distance to central stream, household TWI value), weekend effects and rainfall effects. We included all significant variables in the multivariable model. Thus, both models included gender and age (kept as *a priori* variables), leptospirosis serological status, worker status, study area, weekend effects and rainfall effects.

To analyse the differences in proportion of time spent within the domestic and peri-domestic area we used a weighted mixed-effects logistic regression model. To remove any biases from hours when people sleep, we only looked at GPS points from 5 am to 9 pm. As with the previous two models, this model was weighted by the number of GPS points that each individual had on each day. We also used individual-level random effects to account for the hierarchical nature of the data. The estimates from this model are interpreted as the odds of an individual being within the domestic and peri-domestic area during daytime active hours. To aid reading, the domestic and peri-domestic area will be referred to as domestic space from this point forward.

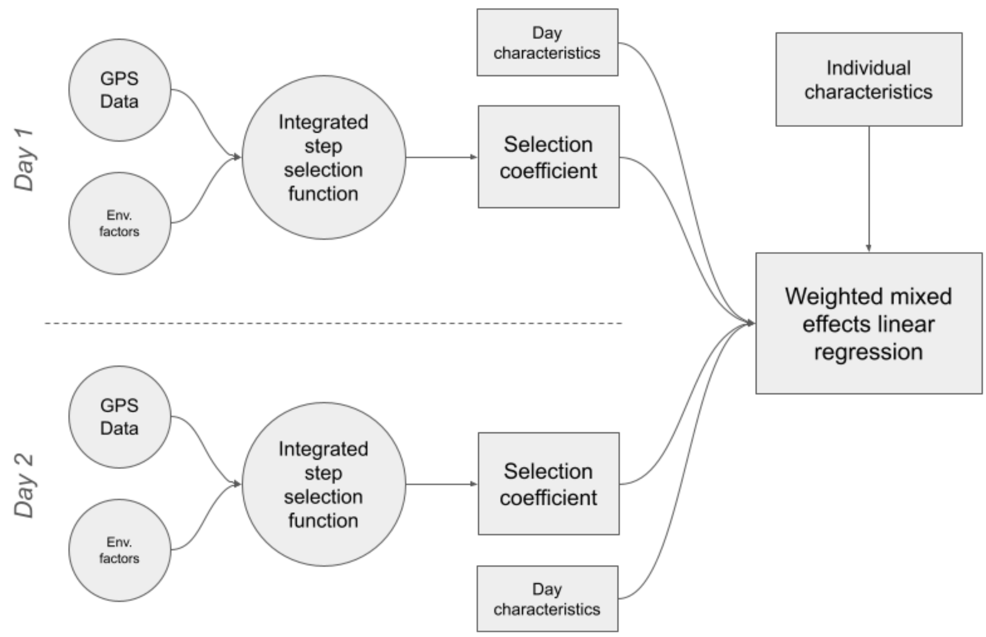


Figure 3.2 Modelling approach for environmental interactions

Our final objective for this research was to understand if there were any differences in how people moved throughout the study areas with regards to open sewer points, domestic rubbish piles, central stream and TWI. Additionally, we were interested to assess if those individuals who had experienced the intervention were displaying different movement behaviours compared to individuals who had had no intervention.

For this, we used a two-phase modelling approach (Figure 3.2). In the first phase (Figure 3.2, circles), the daily individual phase, we used integrated step selection functions on each individual's GPS data on each separate day. The integrated step selection function originates from animal movement ecology and allows us to understand how an individual might choose to interact with a specific environmental factor, accounting for other environmental factors.[25,26] It achieves this by, firstly, creating a set of biologically plausible steps (also called available steps) that the individual could have taken but chose not to, and secondly, comparing the environmental characteristics of used steps against the available steps (Figure 3.3). The available steps are created using specific movement characteristics that each individual is displaying: step lengths and turning angles. The used and available steps are compared in a conditional logistic regression model. The integrated step selection function thus generates selection coefficients for the specific environmental factors. In this case, these were daily selection coefficients, as we were running separate models for each set of daily GPS data that an individual had. We estimated the selection coefficients for open sewer points, domestic rubbish piles, central stream and TWI. For the first three environmental factors, we used both distance-based and buffer-based rasters. Further specifications about the integrated step selection function models can be found in Supplementary Material II.

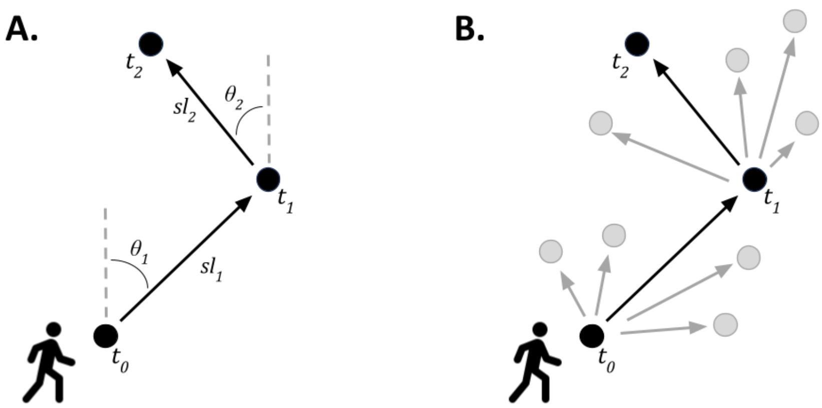


Figure 3.3 Schematic diagram explaining functioning of step selection functions. A, each individual's movement characteristics are computed (step lengths and turning angles). B, movement characteristics are used to create available steps (grey dots) for each used step (black dots

The second phase of this modelling approach (Figure 3.2, rectangles), the population level phase, involved running models for each of the four selection coefficients to analyse if differences existed by a set of factors. We used weighted linear regression models. These models used the direct outputs of the step selection models, which are generated in the log-odds scale. However, to aid interpretation, we present results in the odds scale. Each model included the following variables: gender, age, worker status, leptospirosis serological status, weekend effects, rainfall effects and intervention effects. This final variable was a dummy variable which had a value of 1 for all individuals from NVS during the follow up period (after they had experienced the intervention), and 0 otherwise. The models were weighted by the inverse variance of each of the daily selection coefficients. This meant that the daily selection coefficients that had wider confidence intervals weighed less than those with narrower confidence intervals. More details about this model can be found in Supplementary Material II.

All analyses were carried out in R version 4.5.0[38], using packages {amt}, {lme4}, {broom.mixed}, {terra}, {survival} and those included in {tidyverse}.[39,40,50–53]

3.4 Results

3.4.1 Descriptive Statistics

In this study we had a total of 181 participants across all study areas and collection periods (Table 3.1). We recruited more participants at the follow up periods than at the baseline periods across all areas. There was some loss to follow up, ranging from 22.6 % for NVS to 38.5% for CAL. Across all areas we recruited more women than men. Although we aimed to maintain the approximate ratio of men to women, we only managed this for CAL (57.6 % women at baseline, 56.4 % women at follow up). In NVS, there were more women recruited during the follow up period than during the baseline period (53.3 % women at baseline, 62.3 % women at follow up). In ARE the opposite occurred, we recruited more women during baseline than during follow up (59.3 % women at baseline, 52.5 % women at follow up. The age distribution was approximately the same across all study areas and collection periods.

With regards to recruiting workers, we maintained the ratio of workers to non-workers between collection periods for CAL (30.3 % workers at baseline, 38.5 % workers at follow up). In NVS, we managed to recruit a higher percentage of workers during baseline than during follow up (83.3% vs 52.8%) although the absolute numbers of workers were similar (25 workers vs 28 workers). We saw a similar pattern in ARE, with a higher percentage of workers recruited at baseline compared to follow up (51.9 % vs 42.5%). These skews were caused by recruiting more non-workers during follow up periods in both these study areas. We also had 3 non-respondents: one in NVS at follow up, one in ARE at follow up and one in CAL at baseline. Given the low numbers of non-respondents, these were removed from analyses.

We had an uneven distribution of leptospirosis seropositive individuals in our sample. Although the absolute numbers of seropositive individuals were roughly similar across study areas and collection periods, the percentages represented were highly variable. In ARE, the sample contained the same distribution of seropositive individuals across collection periods (14.8% at baseline vs 15% at follow up). However, the percentages of seropositive individuals were higher in both NVS and CAL (2.7-point increase in NVS and 11.4-point increase in CAL).

Although we had different GPS data collection protocols between baseline and follow up periods, we managed to have a similar distribution of weekend days across both periods and study areas. We had the same difference in mean weekend days in ARE and CAL (0.6 increase in mean number of weekend days from baseline to follow up). The difference in NVS was negligible (0.1 decrease in mean number of weekend days from baseline to follow up).

Table 3.1 Descriptive statistics of participants

		NVS		**ARE**		**CAL**	
		Baseline	**Follow up**	**Baseline**	**Follow up**	**Baseline**	**Follow up**
Total		30	53	27	40	33	39
	Retained participants (%)	-	12 (22.6)	-	14 (35.0)	-	15 (38.5)
Gender	*Female (%)*	16 (53.3)	33 (62.3)	16 (59.3)	21 (52.5)	19 (57.6)	22 (56.4)
Age	*Mean (SD)*	37.5 (14.3)	39.1 (18.2)	42.8 (15.1)	37.9 (17.9)	37.9 (15.4)	35.7 (14.8)
Working	*No (%)*	5 (16.7)	24 (45.3)	13 (48.1)	22 (55.0)	22 (66.7)	24 (61.5)
	Yes (%)	25 (83.3)	28 (52.8)	14 (51.9)	17 (42.5)	10 (30.3)	15 (38.5)
	Don't know / No answer (%)	0 (0.0)	1 (1.9)	0 (0.0)	1 (2.5)	1 (3.0)	0 (0.0)
Leptospirosis serological status	*Positive (%)*	2 (6.7)	5 (9.4)	4 (14.8)	6 (15.0)	3 (9.1)	8 (20.5)
No. Days	*Mean (SD)*	3.5 (1.8)	5.2 (1.6)	4.0 (1.8)	5.9 (1.6)	4.4 (1.8)	6.5 (1.9)
No. Weekends	*Mean (SD)*	1.6 (0.7)	1.5 (0.8)	1.3 (0.7)	1.9 (0.4)	1.0 (0.7)	1.6 (0.7)

The distribution of all rainfall across the study areas was similar (Supplementary Material I – Descriptive statistics). Given the collection periods occurred during different seasons of the year (see Materials and Methods), the number of person-days for each category of rainfall varied across study areas and collection periods (Figure 3.4).

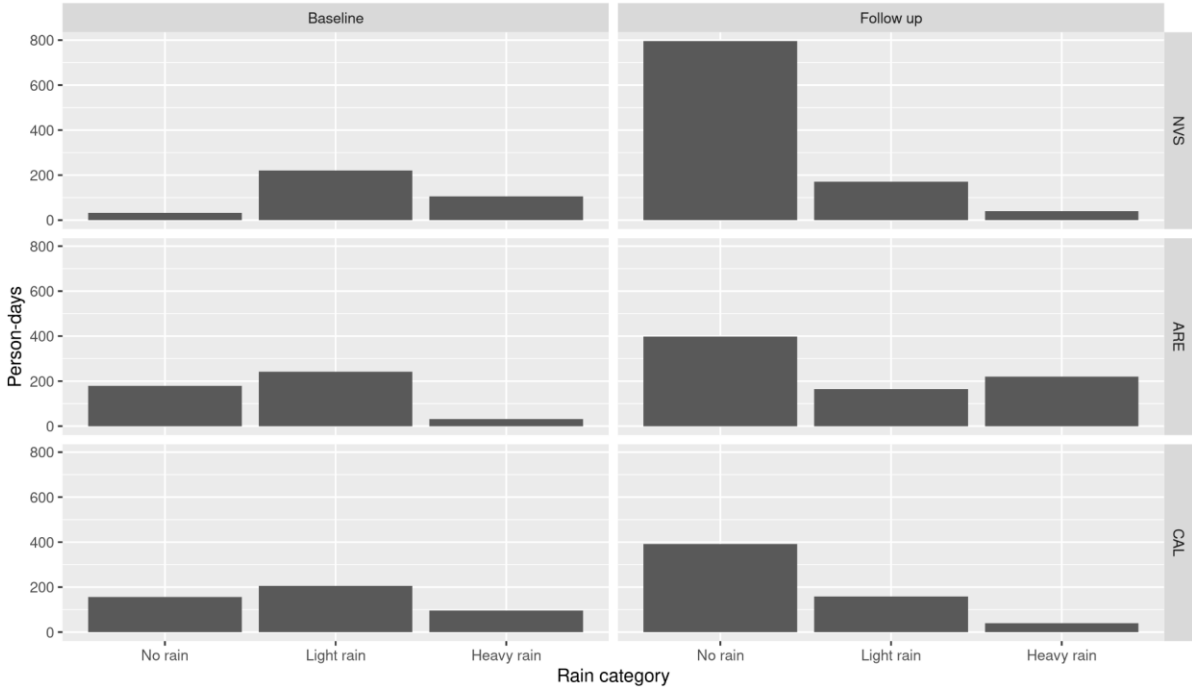


Figure 3.4 Person-days for each type of rain category, by study area and follow up period

3.4.2 Mean daily distance travelled from home

The mean daily distance travelled from home was calculated using all the recorded GPS points for an individual on a given day. The distance from the individual's household and each point was then calculated and the daily mean computed from these values. Overall, the mean daily distance was heavily right skewed. We used the log transformation to be able to better approximate the effects of the variables of interest (Figure 3.5).

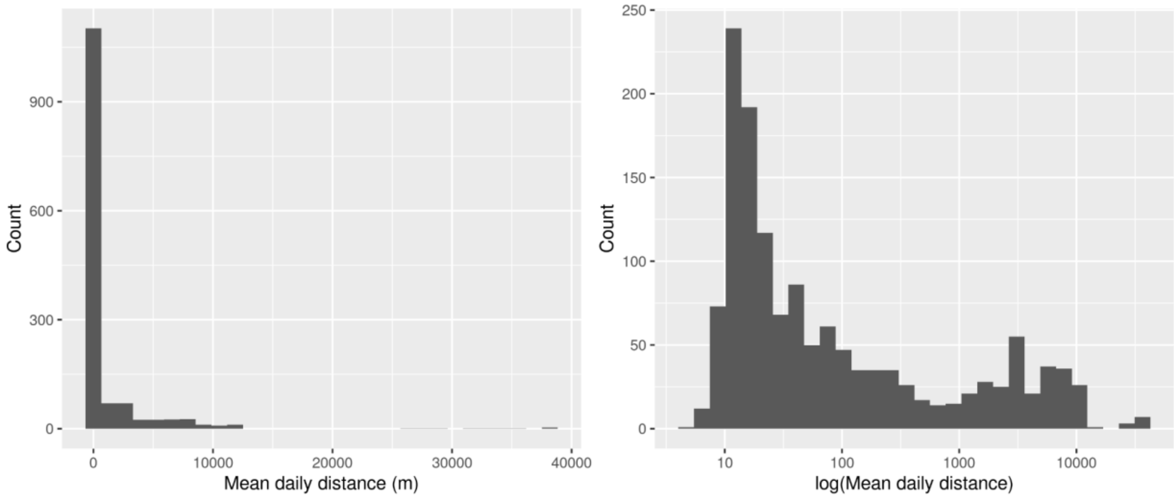


Figure 3.5 Histograms showing distribution of mean daily distance from home, in m. Right hand graph is on the log scale

The final model—a log-transformed mixed effects linear regression, using individual-level random effects—included gender, age, worker status, leptospirosis seropositivity, study area, weekend and rainfall effects as independent variables. Given the log-transformation was used, the results should be interpreted in the multiplicative scale rather than the additive scale. The results discussed below are adjusted for all other variables in the model. Our results showed that there was no evidence for any effects from either gender (estimate: 0.77, 95% CI 0.53 – 1.14, p = 0.195) or age (estimate: 1.00, 95% CI 0.99 – 1.02, p = 0.771). There was strong evidence that workers travelled over 2 times further from their households than non-workers (estimate: 2.19, 95% CI 1.66 – 2.90, p < 0.001). We also saw some significant differences in mean daily distance travelled between the study areas, with residents in both ARE and CAL travelling less than a third than those in NVS (ARE: 0.32, 95% CI 0.19 – 0.54, p < 0.001; CAL: 0.27, 95% CI 0.16 – 0.45, p < 0.001). Participants travelled shorter distances during weekends than during weekdays, approximately 30% less distance (0.72, 95% CI 0.65 – 0.79, p < 0.001). There was strong evidence that residents travelled 30% longer distances during heavy rainfall days compared to no rainfall days (1.31, 95% CI 1.12 – 1.54, p < 0.001). However, there was no evidence of different mean daily distances travelled during light rainfall days compared to no rainfall days (1.03, 95% CI 0.92 – 1.14, p = 0.686). Individuals who were seropositive for leptospirosis travelled over 80% further from home than those who were seronegative (1.88, 95% CI 1.25 – 2.83, p = 0.002).

Table 3.2 Estimated differences and odds ratios for mean daily distances, daily activity space and proportion within domestic area

		Mean daily distance			Daily activity space			Proportion within domestic area		
		Estimate*	**95% CI**	**p**	**Estimate***	**95% CI**	**p**	**OR****	**95% CI**	**p**
Gender	*Female*	Ref			Ref			Ref		
	Male	0.77	0.53 – 1.14	0.195	0.86	0.70 – 1.06	0.167	2.9	2.73 – 3.07	< 0.001
Age		1	0.99 – 1.02	0.771	1	1.00 – 1.01	0.498	0.99	0.97 – 1.00	0.004
Worker status	*Non-worker*	Ref			Ref			Ref		
	Worker	2.19	1.66 – 2.90	< 0.001	1.39	1.18 – 1.63	< 0.001	0.48	0.47 – 0.50	< 0.001
Leptospirosis serological status	*Negative*	Ref			Ref			Ref		
	Positive	1.88	1.25 – 2.83	0.002	1.13	0.89 – 1.44	0.303	4.71	4.37 – 5.08	< 0.001
Study area	*NVS*	Ref			Ref			Ref		
	ARE	0.32	0.19 – 0.54	< 0.001	0.51	0.39 – 0.68	< 0.001	1.81	0.85 – 3.88	0.123
	CAL	0.27	0.16 – 0.45	< 0.001	0.51	0.39 – 0.67	< 0.001	2.96	1.43 – 6.12	0.003
Weekend	*No*	Ref			Ref			Ref		
	Yes	0.72	0.65 – 0.79	< 0.001	0.82	0.77 – 0.87	< 0.001	1.18	1.17 – 1.19	< 0.001
Daily rain category	*No rain*	Ref			Ref			Ref		
	Light rain	1.03	0.92 – 1.14	0.686	0.92	0.86 – 0.99	0.019	1.04	1.03 – 1.05	< 0.001
	Heavy rain	1.31	1.12 – 1.54	0.001	1.27	1.15 – 1.40	< 0.001	0.94	0.93 – 0.96	< 0.001
TWI		-	-	-	-	-	-	1.04	0.97 – 1.12	0.295

** Estimate as multiplicative factor*
*** Odds Ratio*
Ref: Reference category

3.4.3 Daily activity space

All the GPS points for an individual on a given day were buffered and merged. This created a single polygon for which we could calculate the total area used by the individual, which represented the daily activity space. As with mean daily distance travelled from home, the distribution of daily activity space showed a strong right skew, which we normalised by using the log transformation (Figure 3.6).

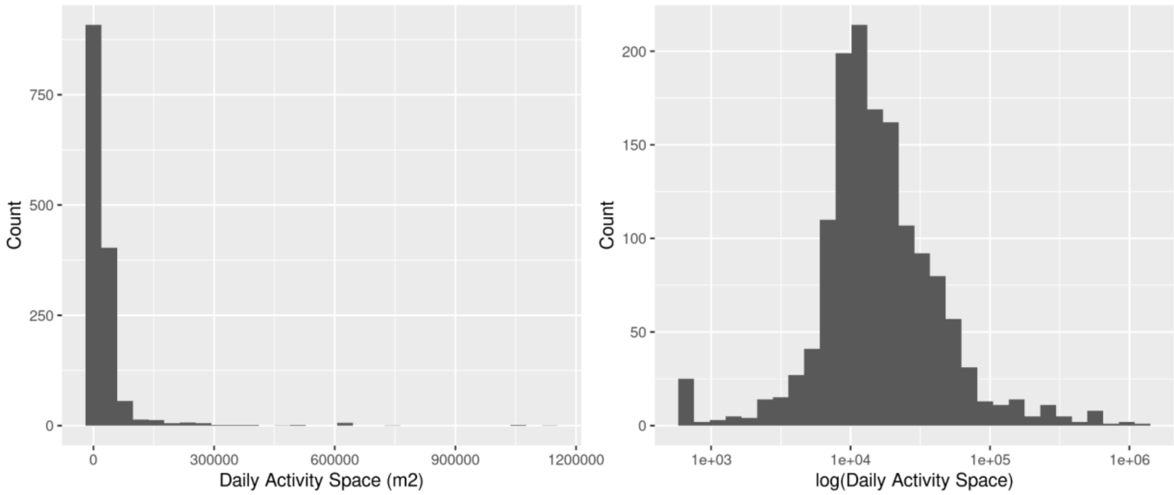


Figure 3.6 Histograms showing distribution of daily activity space, in m2. Right hand plot is on the log scale

We used a log-transformed, mixed-effects linear regression, with individual-level random effects, to estimate the effects of the independent variables on daily activity space. These variables were gender, age, leptospirosis seropositivity, worker status, study area, weekend and rainfall effects. These results are all adjusted for all variables in the model and should be interpreted in the multiplicative scale. Our results showed there was no evidence of any differences in daily activity space between genders (males vs females: 0.86, 95% CI 0.70 – 1.06, p = 0.167), ages (1.00, 95% CI 1.00 – 1.01, p = 0.498) or leptospirosis serological status (positive vs negative: 1.13, 95% CI 0.89 – 1.44, p = 0.303). There was strong evidence that residents would have 20% lower daily activity space during weekend days compared to weekdays (0.82, 95% CI 0.77 – 0.87, p < 0.001). There was also strong evidence that participants would have over 25% higher daily activity space during heavy rainfall days compared to no rainfall days (1.27, 95% 1.15 – 1.40, p < 0.001). Participants also had slightly lower activity space during light rainfall days compared to no rainfall days (0.92, 0.86 – 0.99, p = 0.019).

3.4.4 Proportion within domestic area

We calculated the proportion of time an individual spent within their domestic and peridomestic environment by using the GPS points recorded between 5 am and 9 pm for that individual on a given day. We used the points within a 10-meter buffer of the individual's household to compute the proportion. Calculating the mean proportion over all our sample population across all days showed that individuals would spend just over 25% of their time at home, but there was high variability (mean = 0.26, standard deviation = 0.23).

To model the differences in proportions, we used a weighted mixed-effects logistic regression, with individual-level random effects and weighted by the number of GPS points. Our final model included gender, age, worker status, leptospirosis serological status, study area, weekend effects, rainfall effects and household TWI value as independent variables. The results were adjusted for all other variables included in the model. Results shown should be interpreted as the odds of being within the domestic and peridomestic area between 5 am and 9 pm. To ease understanding, we have simplified this in the text as the odds of being within the domestic area.

Our results showed that men had almost 3 times higher odds of being within the domestic area compared to women (OR 2.90, 95% CI 2.73 – 3.07, $p < 0.001$). Age had a negligible effect (OR 0.99, 95% CI 0.97 – 1.00, $p = 0.004$). Workers had less than half the odds than non-workers (OR 0.48, 95% CI 0.47 – 0.50, $p < 0.001$). Leptospirosis seropositive residents had almost 5 times higher odds of being in the domestic area than seronegative residents (OR 4.71, 95% CI 4.37 – 5.08, $p < 0.001$). We found significant differences in the odds between residents from CAL and those from NVS, with the participants from CAL having almost 3 times higher odds of being at home (OR 2.96, 95% CI 1.43 – 6.12, $p = 0.003$). There were no significant differences between residents from NVS and those from ARE (OR 1.81, 95% CI 0.85 – 3.88, $p = 0.123$). Participants had approximately 20% higher odds of being at home during weekend days than during weekdays (OR 1.18, 95% CI 1.17 – 1.19, $p < 0.001$). Residents had slightly increased odds of being within the domestic area during light rainfall days compared to no rainfall days (OR 1.04, 95% CI 1.03 – 1.05, $p < 0.001$). We saw the same strength of effect in the opposite direction for heavy rainfall days. Residents had a very small reduction of the odds of being at home during heavy rainfall days compared to no rainfall days (OR 0.94, 95% CI 0.93 – 0.96, $p < 0.001$). There was no evidence that the odds of being at home varied as the household TWI value increased (OR 1.04, 95% CI 0.97 – 1.12, $p = 0.295$).

Given the surprising results, namely the gender differences and the effects of heavy rainfall, we performed sub-analyses to assess for any biases. The first sub-analysis we performed was to run the model without the lowest 10% of daily GPS points, to assess if these were skewing the results. The second sub-analysis involved combining the proportion at home data with the activity space data, and removing the lowest 10% of activity space. This accounted for any biases introduced by non-compliant participants who may have left their GPS logger at home during their daily activities. The third sub-analysis involved removing all data points before 22nd April 2022, the date when the Brazilian Ministry of Health declared the end of the health emergency across the country due to the COVID-19 pandemic. The fourth and final sub-analysis used a finer temporal scale to assess if the daily rainfall effects would vary. We found that, although some of the effect sizes moved slightly towards the null, the results were qualitatively the same as the main analysis. The rainfall effects were more pronounced at a finer temporal scale, with the differences between light rainfall periods and no rainfall periods changing direction (OR 0.93, 95% CI 0.92 – 0.94, $p < 0.001$). All results for these sub-analyses are reported in the supplementary materials (Supplementary Material III – Sub-analyses).

3.4.5 Daily environmental selection coefficients

We used step selection functions to assess if there were differences in how individuals moved through their neighbourhood with regards to four environmental factors: open sewer points, domestic rubbish piles, central stream and TWI. These models created a set of selection coefficients for each factor. These selection coefficients represent the relative likelihood that the individual chooses the observed movement steps over plausible alternatives, based on environmental characteristics. They do not measure the absolute probability of entering a zone but rather indicate a behavioural tendency to move through certain types of environments more or less often than expected under a random movement pattern. For this analysis, we used distance-based rasters and buffer-based rasters to assess the interactions with open sewers, rubbish piles and the central stream.

Our analyses showed that there were differences in how individuals chose to move with regards to these environmental factors. Although we analysed both buffer-based rasters and distance-based rasters, the differences for the latter were negligible and will therefore not be discussed below. They are available in Supplementary Material IV – Distance-based raster results. The results for the buffer-based rasters should be interpreted as the relative likelihood of moving into the 20-meter buffer zone for each environmental factor. We have referred to this as the relative selection for this factor.

Regarding open sewer points, our results showed that there were some differences in movement behaviours (Table 3.3). Men had almost 25% higher likelihood of selecting to move into open sewer buffers than women (OR 1.24, 95% CI 1.10 – 1.40, $p < 0.001$). Workers avoided these points compared to non-workers, with over 10% lower odds (OR 0.88, 95% CI 0.78 – 0.99, $p = 0.033$). Residents from CAL had lower odds of selecting to move into open sewer buffers compared to those from NVS (OR 0.71, 95% CI 0.56 – 0.91, $p = 0.007$). There was no evidence of any difference in movement behaviours regarding open sewer points between residents from ARE and NVS (OR 0.80, 95% CI 0.63 – 1.02, $p = 0.076$). Residents had slightly higher odds of moving into open sewer buffers during weekends than during weekdays (OR 1.04, 95% CI 1.01 – 1.08, $p = 0.015$). There was no evidence of different movement behaviours based on age (OR 1.00, 95% CI 0.99 – 1.01, $p = 0.957$), leptospirosis serological status (OR 1.15, 0.99 – 1.34, $p = 0.075$) or daily rainfall category (light rain vs no rain: OR 1.00, 95% CI 0.96 – 1.04, $p = 0.901$; heavy rain vs no rain: OR 0.99, 95% CI 0.95 – 1.04, $p = 0.767$).

Movement behaviours based on domestic rubbish piles showed similar differences. Workers had a lower relative selection of rubbish piles compared to non-workers (OR 0.78, 95% CI 0.61 – 1.00, $p = 0.050$). Residents had lower odds of moving into rubbish pile buffers during weekends than during weekdays (OR 0.91, 95% CI 0.87 – 0.94, $p < 0.001$). They also had higher relative selection of moving into these buffers during heavy rainfall days compared to no rainfall days (OR 1.23, 95% CI 1.16 – 1.31, $p < 0.001$). There was no evidence of different movement behaviours during light rainfall days compared to no rainfall days (OR 1.00, 95% CI 0.96 – 1.05, $p = 0.883$). Similarly, there was no evidence of any variation in movement behaviours with regards to rubbish piles based on gender (males vs females: OR 1.01, 0.75 – 1.37, $p = 0.935$), age (OR 1.00, 95% CI 0.99 – 1.01, $p = 0.602$), leptospirosis serological status (positive vs negative: 1.04, 95% CI 0.58 – 1.86, $p = 0.904$) or study area (ARE vs NVS: 1.06, 95% CI 0.70 – 1.62, $p = 0.772$; CAL vs NVS: OR 1.47, 95% CI 0.98 – 2.20, $p = 0.062$).

There were some differences in movement behaviours regarding the central stream, although not as many as the previous environmental factors. Residents in ARE had over 50% higher odds of selecting to move into the central stream buffer than those in NVS (OR 1.51, 95% CI 1.17 – 1.93, $p = 0.001$). There was no evidence of any differences between residents living in CAL and residents living in NVS (OR 1.06, 95% CI 0.82 – 1.37, $p = 0.640$). There was strong evidence that participants had a higher relative selection for the central stream during heavy rainfall days compared to no rainfall days (OR 1.11, 95% CI 1.05 – 1.17, p < 0.001). However, we found no evidence of differences between light rainfall days and no rainfall days (OR 1.02, 95% CI 0.98 – 1.06, p = 0.298). We also found no evidence of different movement behaviours regarding the central stream based on gender (males vs females: OR 0.91, 95% CI 0.77 – 1.08, p = 0.269), age (OR 1.00, 0.99 – 1.00, 0.496), worker status (worker vs non-worker: OR 0.93, 95% CI 0.84 – 1.03, p = 0.155), leptospirosis serological status (positive vs negative: OR 1.03, 95% CI 0.78 – 1.36, p = 0.812) or day of the week (weekend vs weekday: OR 0.99, 95% CI 0.95 – 1.02, p = 0.427).

Our results showed no major differences in movement behaviours based on the environmental TWI (Table 3.3). Although there was evidence of a minor difference in movement behaviour between heavy rainfall days and no rainfall days, we considered it negligible and therefore non-significant (OR 1.01, 95% CI 1.00 – 1.01, p = 0.005).

When comparing residents who experienced the intervention to those who did not, we saw some differences in their movement behaviours. There was strong evidence that intervention participants had a third less relative selection for open sewer points than control (non-intervention) participants (OR 0.65, 95% CI 0.58 – 0.72, p < 0.001). Intervention participants had almost 50% higher odds of moving into domestic rubbish pile buffers (OR 1.45, 95% CI 1.35 – 1.55, p < 0.001) and over 20% higher odds of moving into the central stream buffer (OR 1.22, 95% CI 1.10 – 1.36, p< 0.001) than control participants. There was no evidence of any differences in movement behaviours based on TWI (OR 1.01, 95% CI 1.00 – 1.02, p = 0.272).

Table 3.3 Estimated differences in selection coefficients for each environmental factor

		Open Sewers*			Domestic rubbish piles*			Central Stream*			TWI		
		OR	**95% CI**	**p**	**OR**	**95% CI**	**p**	**OR**	**95% CI**	**p**	**OR**	**95% CI**	**p**
Gender	*Female*	Ref			Ref			Ref			Ref		
	Male	1.24	1.10 – 1.40	<0.001	1.01	0.75 – 1.37	0.935	0.91	0.77 – 1.08	0.269	1	0.99 – 1.01	0.528
Age		1	0.99 – 1.01	0.957	1	0.99 – 1.01	0.602	1	0.99 – 1.00	0.496	1	1.00 – 1.00	0.762
Worker status	*Non-worker*	Ref			Ref			Ref			Ref		
	Worker	0.88	0.78 – 0.99	0.033	0.78	0.61 – 1.00	0.05	0.93	0.84 – 1.03	0.155	1	0.99 – 1.01	0.391
Leptospirosis serological status	*Negative*	Ref			Ref			Ref			Ref		
	Positive	1.15	0.99 – 1.34	0.075	1.04	0.58 – 1.86	0.904	1.03	0.78 – 1.36	0.812	0.99	0.98 – 1.01	0.251
Study area	*NVS*	Ref			Ref			Ref			Ref		
	ARE	0.8	0.63 – 1.02	0.076	1.06	0.70 – 1.62	0.772	1.51	1.17 – 1.93	0.001	1	0.99 – 1.02	0.574
	CAL	0.71	0.56 – 0.91	0.007	1.47	0.98 – 2.20	0.062	1.06	0.82 – 1.37	0.64	1	0.98 – 1.02	0.885
Weekend	*No*	Ref			Ref			Ref			Ref		
	Yes	1.04	1.01 – 1.08	0.015	0.91	0.87 – 0.94	<0.001	0.99	0.95 – 1.02	0.427	1	1.00 – 1.00	0.189
Daily rain category	*No rain*	Ref			Ref			Ref			Ref		
	Light rain	1	0.96 – 1.04	0.901	1	0.96 – 1.05	0.883	1.02	0.98 – 1.06	0.298	1	1.00 – 1.00	0.615
	Heavy rain	0.99	0.95 – 1.04	0.767	1.23	1.16 – 1.31	<0.001	1.11	1.05 – 1.17	<0.001	1.01	1.00 – 1.01	0.005
Intervention	*No intervention*	Ref			Ref			Ref			Ref		
	Intervention	0.65	0.58 – 0.72	<0.001	1.45	1.35 – 1.55	<0.001	1.22	1.10 – 1.36	<0.001	1.01	1.00 – 1.02	0.272

**Buffer-based rasters used. Values > 1 represent higher odds of entering the 20-meter buffer for each factor*
OR - Odds Ratio
Ref - Reference category

3.5 Discussion

Understanding movement patterns of urban residents represents an important addition to the knowledge of the epidemiology of leptospirosis. In this study we aimed to investigate the movement behaviours of residents from three urban slums in Salvador, Brazil. We analysed how much time they spent within their domestic and peri-domestic environment, how far they travelled from their homes, how much space they used during their daily activities and how they interacted with a set of environmental factors, which were known risk factors for leptospirosis.

Our results showed that men had higher relative selection for open sewers than women. They also showed that they had higher odds of being within the domestic environment throughout the day than women, with no evidence of any gender differences in daily mean distance travelled from home or daily activity space. Whilst the first result was expected and followed previous research, we found the second result surprising. We hypothesise that this result could have arisen due to different socialising patterns between men and women. We believe women may socialise more outside of the house, in community spaces, whereas men may socialise in or near their households. Additionally, women may be more responsible for chores or activities outside of the household. The gender differences in movement behaviours regarding open sewers follows previous work carried out by the authors and collaborators.[18,54] Men have been shown to have higher risk of becoming infected with leptospirosis and generally have less knowledge and worse attitudes towards the disease.[10,18] Further qualitative studies are needed to develop a better understanding of how these differences may arise.

These results contrast with the findings reported by Owers et al, 2018, who found no gender differences regarding how much time participants spent near their residence. They also found that men had higher daily activity spaces than women. The differences in findings can be attributed to various factors. Firstly, we had a larger sample population than Owers et al., 2018, who we followed for longer periods of time. The larger sample could have allowed a better estimation of true differences. Secondly, Owers et al, 2018, carried out their study in a different site to the ones used in this paper. Although they were socio-demographically comparable, there could have been some underlying differences that could have altered the results. Thirdly, and likely the most important, we used a more sophisticated model that allowed us to adjust for other variables, such as worker status or day of the week.

The pattern of movements of workers compared to non-workers followed what we expected. They travelled further, spent less time at home and had lower relative selection of open sewers and rubbish piles. Although not captured by the data presented in this study, we know that most workers in these communities travel outside of their neighbourhoods for their jobs. Additionally, these jobs tend to be precarious. Therefore, we hypothesise that workers are likely more cautious with their environmental exposure and therefore avoiding risky areas. Another hypothesis is that non-workers are carrying out more household chores, which could be forcing them to interact more with the open sewer points and rubbish piles in their communities.

The results regarding differences in movement patterns during different rainfall categories were also unexpected. We found that during heavy rainfall days, participants would travel further, have higher activity spaces and have slightly lower odds of being within the domestic space compared to no rainfall days. The results also indicated that residents had lower activity spaces and higher odds of being at home during light rainfall days compared to no rainfall days. We believe that one of the driving factors for the effects of heavy rainfall could be the increased difficulties in travelling through the city during these types of days. More congested traffic combined with lower speeds means residents spend less time at home during these days. Additionally, access to the study areas can become complicated due to heavy water flow through streets and increased flooding. Therefore, residents have to find alternative routes through their neighbourhood, which could result in increased distances and activity spaces. These effects are not as pronounced during light rainfall days, which explains the different results between these types of days. We initially believed that household characteristics could be modulating the effects of heavy rainfall. Our hypothesis was that residents living in areas more prone to flooding or closer to the central stream would be leaving their houses during heavy rainfall to find safer spaces. However, our sub-analyses showed that there were no differences based on these household characteristics.

There was evidence that leptospirosis seropositive individuals travelled further and had higher odds of being at home compared to seronegative individuals. Although these results might appear contradictory, we believe these results could be explained by occasional visits to hospital or other medical centres from ill individuals. It is important to highlight that seropositive individuals do not necessarily have an active infection. Their positive MAT test indicates that they have antibodies against leptospirosis bacteria, which could have followed after a symptomatic or asymptomatic infection. The exact duration of antibodies following leptospiral infection still remains unknown, although research has estimated that it could last over 8 years.[11] Therefore, it is difficult to determine when the infection occurred. Furthermore, given the serological samples were collected before the mobility data, it is impossible to assign a causal link from movement to seropositivity.

Another important result to highlight is the difference between participants who experienced the intervention and those who did not. As a reminder, given the structure of our sampling, we have individuals in our population from both before the intervention and after the intervention. These repeated samplings from the same individuals are accounted for by the mixed-effects models. Our results showed that the intervention participants had lower relative selection of open sewers compared to the non-intervention participants. There also was evidence that they had higher relative selection of both rubbish piles and the central stream. We believe the first effect, the relative avoidance of open sewers, could be due to the intervention itself, as it involved community engagement to increase awareness of leptospirosis risk factors. However, we are unsure why intervention participants would be interacting more with rubbish piles and the central stream. Further research is needed to fully ascertain if there is a causal link between the intervention and individual behaviours.

3.5.1 Strengths and limitations

One of the biggest strengths of this research is the richness of the movement data. We were able to record GPS data over long periods of days in different months. This allowed us to capture any variability that could be occurring due to the days of the week or due to different seasons. The high sampling frequency used for the GPS loggers also allowed us to look at fine-scale movements. These types of movements are important in tropical urban areas like the ones in our study, as the landscape can change drastically over short distances.

Another important strength is the possibility to model movement choice by using step selection functions. Although movement behaviours and choice likely have other important factors that are not captured in this work, we believe that the step selection functions provide an approximation to an individual's behaviour. Comparing biologically plausible steps that were not used to those that an individual did use, we can see how the surrounding environments might affect one's choice to move into it.

Our study also contained limitations which are crucial to highlight. Although we managed to increase recruitment into the study during the first follow up period, there was important loss to follow up. This affected our ability to fully analyse the intervention effects, as it limited the internal validity of this research objective. Similarly, the limited studies using GPS loggers for human mobility research and the lack of research performing power analyses for these meant that we could not perform a scientifically proven calculation for our sample size. Therefore, we opted to use a sample based on our available resources and balanced by gender. This could have resulted in an underpowered study which could affect the interpretability of our results. Additionally, given the sample size and characteristics, the generalizability of the study is limited to residents from similar neighbourhoods in Salvador, Brazil. Further research is needed in other environments to improve understanding of movement behaviours across geographies.

Another important limitation was the change in GPS data collection protocol. We collected GPS data at higher frequencies during the baseline periods than during the follow up periods. This change was carried out to prolong battery life and therefore extend the period of GPS data collection. We attempted to account for this difference throughout our analyses, weighting by the number of GPS points and using individual-level step selection functions separately. However, the change in sampling frequency could have affected the environmental interactions captured by the data. Longer sampling periods could have resulted in lower relative selections being recorded. Nevertheless, we believe that we accounted for the different protocol sufficiently to minimise any unintended underestimation of effects.

Whilst the use of step selection functions provided some valuable strengths to the research, they also came with assumptions and limitations. Firstly, one of the underlying assumptions was that by introducing step lengths and turning angles into the individual-level step selection model, we accounted for intentional destination-seeking movement. Although these models were not designed with this type of movement in mind, we believe our model sufficiently adjusts for it. Secondly, step selection functions assume smooth movement through the environment. This does not hold true through urban landscapes, which contain sharp angles caused by street layouts. The effects of violating this assumption require further research and are outside of the scope of this study. Thirdly, the biologically plausible steps that are created in the step selection function could also be structurally impossible. In other words, a step could be biologically possible due to the length and turning angle but may be structurally impossible if it requires moving through a wall or into a stranger's house. Additionally, it is important to highlight that movement choices can be affected by a large range of factors that are not recorded in this research, such as structural components (e.g. having to cross a bridge) or social components (e.g. avoiding a violent area). Daily qualitative interviews could supplement the GPS telemetry data collected to give a more complete picture of the choices an individual made in their movement route. These limitations also combine to complicate the interpretation of results. Although it is tempting to interpret the selection coefficients as the odds of interacting with a specific environmental point, this risks oversimplifying these values in the context of human mobility given the range of factors that can modulate it. As mentioned previously, these coefficients represent the relative selection of a specific environmental characteristic, comparing the observed steps with alternative plausible ones. Whilst they offer valuable insights, interpreting these results as intentional environmental interaction should be done with care and, ideally, coupled with individual interviews.

3.5.2 Conclusion

This study makes use of high-resolution GPS data to analyse human movement patterns in a tropical urban setting in Salvador, Brazil. We showed that residents' movement patterns vary depending on socio-demographic factors. This is also true for how much time they spend at home and how they interact with the surrounding environment. This highlights important limitations of using household-based models for environmental risk estimation. Further research is needed to understand why and how these differences are arising. Our results provide a good primer for qualitative studies to investigate this further.

3.6 Supplementary Material I – Descriptive statistics

3.6.1 Rainfall

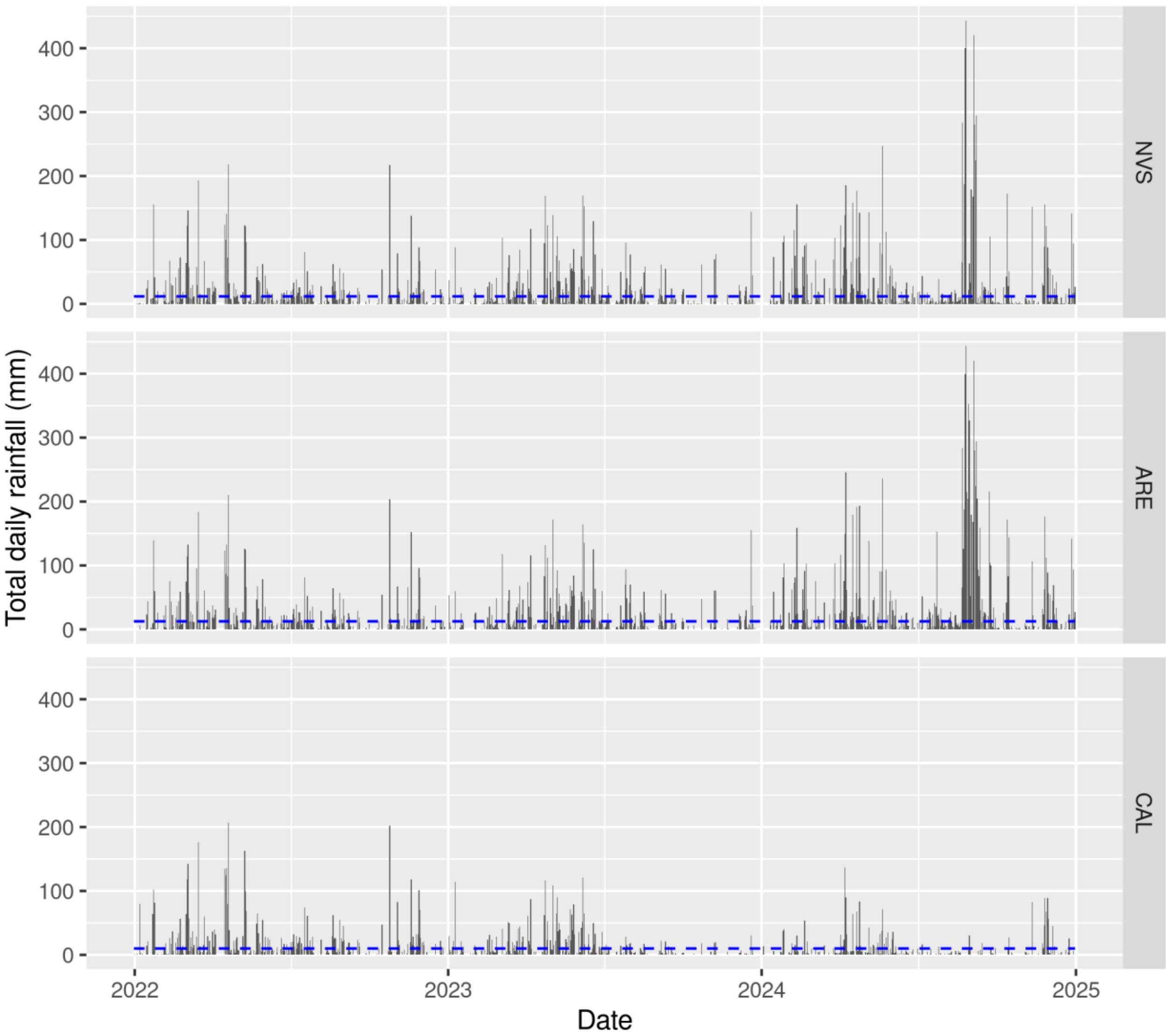


Figure 3.7 Total daily rainfall in mm for each study area. Blue dotted line represents 75th percentile of daily rainfall for each area, which is used to categorise days into light rain or heavy rain

3.7 Supplementary Material II – Model specifications

3.7.1 Integrated step selection function

The conditional logistic regression model used for the individual-level integrated step selection functions is defined by the following equation:

$$logit(p) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_6 x_6 + \beta_7 x_7 + \beta_8 x_8 + \alpha_{stratum_j}$$

Where the first four variables ($x_1 - x_4$) represent the environmental factors being analysed (open sewer points, rubbish piles, central stream and TWI), along with their respective selection coefficients ($\beta_1 - \beta_4$). Both distance-based and buffer-based rasters are used for these variables, in separate models. To account for household location relative to the other environmental factors, we included a household buffer raster as the fifth variable (x_5). The next three variables ($x_6 - x_8$) capture the movement characteristics of each individual: the step length, the log(step length) and the cosine of the turning angle. The model was stratified by each used step ($\alpha_{stratum_i}$), where j represents each used step and its associated available steps.

3.7.2 Population-level models

The weighted mixed-effects linear regression model used to assess differences in selection coefficients is defined by the following equation:

$$\hat{\beta_k} = \gamma_0 + \gamma_1 x_1 + \gamma_2 x_2 + \gamma_3 x_3 + \gamma_4 x_4 + \gamma_5 x_5 + \gamma_6 x_6 + \gamma_7 x_7 + Z_k + \varepsilon$$

Here, we are modelling the estimated selection coefficient for a specific environmental factor (k), given by $\hat{\beta_k}$, as the outcome variable. The model includes the following explanatory variables: gender, age, worker status, leptospirosis serological status, weekend effects, rainfall effects and intervention effects ($x_1 - x_7$). The error term, Z_k, capture the residuals from the model, which also account for any variation between individuals which was not measured as well as the sampling error inherent to the estimates of the selection coefficients. To account for variation in the standard errors of the selection coefficients, the variance of Z_k was defined as w_k/τ^2, where w_k is the estimated variance of $\hat{\beta_k}$ which was used to account for the heterogeneity in the estimate of $\hat{\beta_k}$. The individual-level fixed effects are represented by ε.

3.8 Supplementary Material III – Sub-analyses

3.8.1 Sub-analysis 1: Remove data rows with 10% lowest GPS points

		OR*	95% CI	p
Gender	Female	Ref		
	Male	2.95	2.78 – 3.13	< 0.001
Age		0.99	0.97 – 1.00	0.108
Worker status	Non-worker	Ref		
	Worker	0.46	0.44 – 0.47	< 0.001
Leptospirosis serological status	Negative	Ref		
	Positive	4.72	4.38 – 5.09	< 0.001
Study area	NVS	Ref		
	ARE	1.84	0.84 – 4.01	0.126
	CAL	2.93	1.40 – 6.15	0.004
Weekend	No	Ref		
	Yes	1.17	1.16 – 1.18	< 0.001
Daily rain category	No rain	Ref		
	Light rain	1.03	1.02 – 1.05	< 0.001
	Heavy rain	0.96	0.94 – 0.97	< 0.001
TWI		1.03	0.96 – 1.11	0.425

** Odds of being within the domestic area*
OR - Odds Ratio
Ref - Reference category

3.8.2 Sub-analysis 2: Remove data rows with 10% lowest activity space

		OR*	95% CI	p
Gender	Female	Ref		
	Male	2.5	2.35 – 2.65	< 0.001
Age		0.99	0.98 – 1.00	0.088
Worker status	Non-worker	Ref		
	Worker	0.53	0.50 – 0.55	< 0.001
Leptospirosis serological status	Negative	Ref		
	Positive	4.67	4.34 – 5.04	< 0.001
Study area	NVS	Ref		
	ARE	1.81	0.86 – 3.82	0.119
	CAL	3.13	1.53 – 6.41	0.002
Weekend	No	Ref		
	Yes	1.2	1.19 – 1.21	< 0.001
Daily rain category	No rain	Ref		
	Light rain	1.05	1.04 – 1.06	< 0.001
	Heavy rain	0.98	0.96 – 0.99	0.002
TWI		1.04	0.97 – 1.12	0.235

** Odds of being within the domestic area*
OR - Odds Ratio
Ref - Reference category

3.8.3 Sub-analysis 3: Remove data pre-April 2022

		OR*	95% CI	p
Gender	Female	Ref		
	Male	2.78	2.63 – 2.95	< 0.001
Age		0.97	0.95 – 0.98	< 0.001
Worker status	Non-worker	Ref		
	Worker	0.48	0.46 – 0.50	< 0.001
Leptospirosis serological status	Negative	Ref		
	Positive	4.71	4.37 – 5.08	< 0.001
Study area	NVS	Ref		
	ARE	0.92	0.43 – 1.93	0.815
	CAL	1.4	0.68 – 2.88	0.362
Weekend	No	Ref		
	Yes	1.14	1.13 – 1.15	< 0.001
Daily rain category	No rain	Ref		
	Light rain	1.03	1.02 – 1.04	< 0.001
	Heavy rain	0.93	0.92 – 0.95	< 0.001
TWI		1.04	0.97 – 1.12	0.224

** Odds of being within the domestic area*
OR - Odds Ratio
Ref - Reference category

3.8.4 Sub-analysis 4: Finer temporal resolution

		OR*	95% CI	p
Gender	Female	Ref		
	Male	2.74	2.58 – 2.91	< 0.001
Age		0.94	0.93 – 0.95	<0.001
Worker status	Non-worker	Ref		
	Worker	0.95	0.89 – 1.00	0.049
Leptospirosis serological status	Negative	Ref		
	Positive	0.78	0.72 – 0.85	< 0.001
Study area	NVS	Ref		
	ARE	3.78	1.37 – 10.40	0.01
	CAL	4.65	1.77 – 12.20	0.001
Weekend	No	Ref		
	Yes	1.1	1.09 – 1.11	< 0.001
Daily rain category	No rain	Ref		
	Light rain	0.93	0.92 – 0.94	< 0.001
	Heavy rain	0.81	0.80 – 0.83	<0.001
TWI		1.05	0.95 – 1.15	0.331
Period	Morning	Ref		
	Midday	0.89	0.88 – 0.90	<0.001
	Afternoon	0.68	0.68 – 0.69	<0.001
	Evening	0.71	0.70 – 0.72	<0.001

** Odds of being within the domestic area*
OR - Odds Ratio
Ref - Reference category

3.9 Supplementary Material IV – Distance-based raster results

3.9.1 Open sewers

		OR	95% CI	p
Gender	Female	Ref		
	Male	1.01	0.95 – 1.00	0.165
Age		1	1.00 – 1.02	0.552
Worker status	Non-worker	Ref		
	Worker	0.99	0.98 – 1.00	0.174
Leptospirosis serological status	Negative	Ref		
	Positive	1.05	1.04 – 1.07	<0.001
Study area	NVS	Ref		
	ARE	1.02	1.00 – 1.04	0.12
	CAL	0.99	0.97 – 1.01	0.301
Weekend	No	Ref		
	Yes	1	1.00 – 1.00	0.369
Daily rain category	No rain	Ref		
	Light rain	1	1.00 – 1.00	0.502
	Heavy rain	1	1.00 – 1.01	0.739
Intervention	No intervention	Ref		
	Intervention	1.01	1.00 – 1.02	0.032

OR - Odds Ratio
Ref - Reference category

3.9.2 Domestic rubbish piles

		OR	95% CI	p
Gender	Female	Ref		
	Male	1.02	1.01 – 1.02	<0.001
Age		1	1.00 – 1.00	0.073
Worker status	Non-worker	Ref		
	Worker	1	0.99 – 1.00	0.319
Leptospirosis serological status	Negative	Ref		
	Positive	0.98	0.98 – 0.99	<0.001
Study area	NVS	Ref		
	ARE	1	0.99 – 1.00	0.556
	CAL	1.02	1.01 – 1.04	0.006
Weekend	No	Ref		
	Yes	1	1.00 – 1.00	0.001
Daily rain category	No rain	Ref		
	Light rain	1	1.00 – 1.00	0.993
	Heavy rain	1	1.00 – 1.01	0.041
Intervention	No intervention	Ref		
	Intervention	1.01	1.00 – 1.01	0.027

OR - Odds Ratio
Ref - Reference category

3.9.3 Central stream

		OR	95% CI	p
Gender	Female	Ref		
	Male	1	0.99 – 1.01	0.78
Age		1	1.00 – 1.00	0.781
Worker status	Non-worker	Ref		
	Worker	1.01	1.00 – 1.02	0.014
Leptospirosis serological status	Negative	Ref		
	Positive	0.97	0.96 – 0.98	<0.001
Study area	NVS	Ref		
	ARE	0.98	0.97 – 1.00	0.02
	CAL	1.01	0.99 – 1.03	0.227
Weekend	No	Ref		
	Yes	1	1.00 – 1.00	0.263
Daily rain category	No rain	Ref		
	Light rain	1	1.00 – 1.00	0.897
	Heavy rain	1	1.00 – 1.01	0.857
Intervention	No intervention	Ref		
	Intervention	1	0.99 – 1.00	0.148

OR - Odds Ratio
Ref - Reference category

3.9.4 TWI

Adjusted for distance-based rasters of all other environmental variables

		OR	95% CI	p
Gender	Female	Ref		
	Male	0.99	0.98 – 1.00	0.082
Age		1	1.00 – 1.00	0.957
Worker status	Non-worker	Ref		
	Worker	1	0.99 – 1.01	0.496
Leptospirosis serological status	Negative	Ref		
	Positive	0.98	0.98 – 0.99	<0.001
Study area	NVS	Ref		
	ARE	1	0.98 – 1.02	0.966
	CAL	1	0.99 – 1.02	0.669
Weekend	No	Ref		
	Yes	1	1.00 – 1.00	0.062
Daily rain category	No rain	Ref		
	Light rain	1	1.00 – 1.00	0.668
	Heavy rain	1.01	1.00 – 1.01	0.002
Intervention	No intervention	Ref		
	Intervention	1.01	1.00 – 1.02	0.218

OR - Odds Ratio
Ref - Reference category

Chapter 4 Collaborative mapping: Perceived environmental risk of leptospirosis in urban communities in Salvador, Brazil

Fabiana Almerinda G. Palma[1]†, **Pablo Ruiz Cuenca[2]†**, Hussein Khalil[3]; Patrícia Lustosa Brito[4], Marbrisa Nascimento Reis das Virgens[4]; Murilo Guerreiro Arouca[5], Alexandre Mota Santos[1], Daiana Santos de Oliveira[1,8], Yeimi Alexandra Alzete Lòpez[1], Diogo César de C. Santiago[6] Michael Begon[7]; Emanuele Giorgi[2], Federico Costa[1,8*], and Ricardo Lustosa[9]†

[1]*Institute of Collective Health, Federal University of Bahia, Canela, Salvador, Bahia, Brazil*

[2]*Centre for Health Informatics, Computing and Statistics (CHICAS), Health Innovation One, Lancaster University, Lancaster, LA1 4AT*

[3] *Department of Wildlife, Fish, and Environmental Studies, Swedish University of Agricultural Sciences, Umeå, Sweden*

[4] *Polytechnic School, Federal University of Bahia, Salvador, Bahia, Brazil*

[5] *Institute of Computing, Federal University of Bahia, Salvador, Bahia, Brazil*

[6] *Departamento de Medicina Preventiva e Social, Faculdade de Medicina da Bahia, Federal University of Bahia*

[7] *Department of Evolution, Ecology and Behaviour, The University of Liverpool, United Kingdom*

[8] *Instituto Gonçalo Moniz, Fundação Oswaldo Cruz, Ministério da Saúde, Salvador, Bahia, Brazil*

[9] *Federal University of Western Bahia - Campus Barra, Bahia, Brazil*

† These authors contributed equally to this work.

4.1 Abstract

Background: Environmental risks represent a threat that can disproportionately affect populations in situations of social vulnerability. Despite its importance, most studies on urban leptospirosis have not captured residents' perceptions of these risks. Collaborative mapping can provide spatial information on relevant environmental factors for leptospirosis.

Methods: We conducted a cross-sectional study between August 2018 and March 2019 using the collaborative mapping approach to explore residents' perceptions of environmental health risks.

Results: The majority of participants identified sewage as the main health risk (AC: 33.6%, MR: 32.5%, NC: 27.5%, RS: 39.2%), followed by garbage (AC: 28.1%, MR: 27.2%, NC: 21.5%, RS: 27.5%). Leptospirosis was perceived as a high-risk problem by a smaller proportion of participants (AC: 0.0%, MR: 1.0%, NC: 3.8%, RS: 2.5%). We found no concordance between areas perceived as high risk and households testing positive for leptospirosis, nor between high rat risk and positive rat traps and track plates.

Conclusions: We found a higher density of rubbish piles in high rubbish risk areas. Collaborative mapping is an effective method for capturing individual perceptions of environmental health risks, promoting community participation in the co-construction of valuable information for the more effective prevention and control of diseases such as leptospirosis. However, resident perceptions did not match spatial areas of *Leptospira* transmission. This may be related to the fact that residents' concerns are more focused on the determinants of *Leptospira* transmission and not necessarily the disease, which could be further explored in future studies.

Keywords: Leptospirosis; Collaborative Mapping; Environmental Risk; Poverty Areas.

4.2 Introduction

Environmental risks pose a significant threat to populations in situations of social vulnerability, exposing them to a wide range of zoonotic diseases [55]. Leptospirosis, a neglected zoonosis [56] transmitted through contact with contaminated water and mud [57], is a significant health risk and is strongly influenced by environmental factors [55,58,59] such as waste and poor sewage systems, both of which result from inadequate basic sanitation.[60] Previous studies using quantitative and spatial methodologies have reported various environmental risk factors for leptospirosis, such as residences in flood-prone areas, proximity to open sewage, sightings of rats, contact with mud, and inadequate sanitation.[58,61] Despite their importance, these studies have not considered the perceptions of people living in areas with these risks and the influence of their personal experiences, those of other family members, and the community on the characteristics of their territory, as well as media reports.[62]

In Brazil, there is a need to understand the perception of risk by residents living in communities exposed to a wide range of preventable environmental risk factors that cause diseases such as leptospirosis. Using participatory methods to determine residents' perceptions based on a critical view of the environment can contribute to people living in these contexts' awareness and engagement.[63] This is especially needed in populations exposed to numerous environmental risks, which tend to be amplified by population growth in areas with inadequate infrastructure and sanitation[60], and the emergence and re-emergence of diseases associated with environmental risk factors.[64]

Assessing environmental risk perception to mitigate its effects on human life and reduce the risk of diseases can be accomplished by adopting participatory methodologies such as collaborative mapping. This method promotes community participatory work and the development of an understanding of existing local resources and the environmental problems that affect them.[65] Collaborative mapping activities are guided by the environmental context and how groups interpret their environment based on their daily experiences.[66] This allows residents and researchers to reflect more deeply on the environment being studied[67] and identify more effective and sustainable ways to intervene in existing risks. Previous studies using collaborative mapping have contributed to identifying environmental risks such as floods[68], volcanic risk [69], flooding and landslides [70], mangrove ecosystem services [71], and measured the risk environment of female sex workers in the Dominican Republic [72]. The participatory approach can be fundamental for creating responses, indicating community-based interventions, and providing the community with access to information that can support claims for public policies aimed at necessary improvements in their environment.

In most studies conducted in urban informal settlements, traditional spatial methodologies have been used to identify environmental risk factors for leptospirosis [58,61]. The methods have involved recall from residents but have not captured their perceptions of the surrounding environment. Capturing these perceptions could be a useful tool in understanding how the community understands the environmental risks they are exposed to and could enhance researchers understanding of the links between environmental factors and leptospirosis risk. Therefore, we aim to analyse the perception of environmental health risks through collaborative mapping, focusing on the factors contributing to leptospirosis in four peripheral communities of Salvador, Brazil.

4.3 Materials and Methods

4.3.1 Study area

Our study was part of a project initiated in 2017 in four urban informal settlements.[55] These communities, known as Marechal Rondon (MR), Alto do Cabrito (AC), Nova Constituinte (NC), and Rio Sena (RS), are situated in the periphery of Salvador, a city of 2.417.678 million inhabitants in 2022 [73] in Bahia, Northeast Brazil (Figure 4.1). They have similar characteristics: low family income, densely populated settlements; and precarious infrastructure, sanitation, and public service offerings, such as healthcare and public transport.[60] Furthermore, previous studies in this area indicated that an unadjusted seroprevalence for *Leptospira* in MR, AC, NC and RS was 11% (n=338), 10% (n=375), 9% (n=306), 12% (n=299), respectively [55], which characterizes these sites as being at risk for leptospirosis transmission.

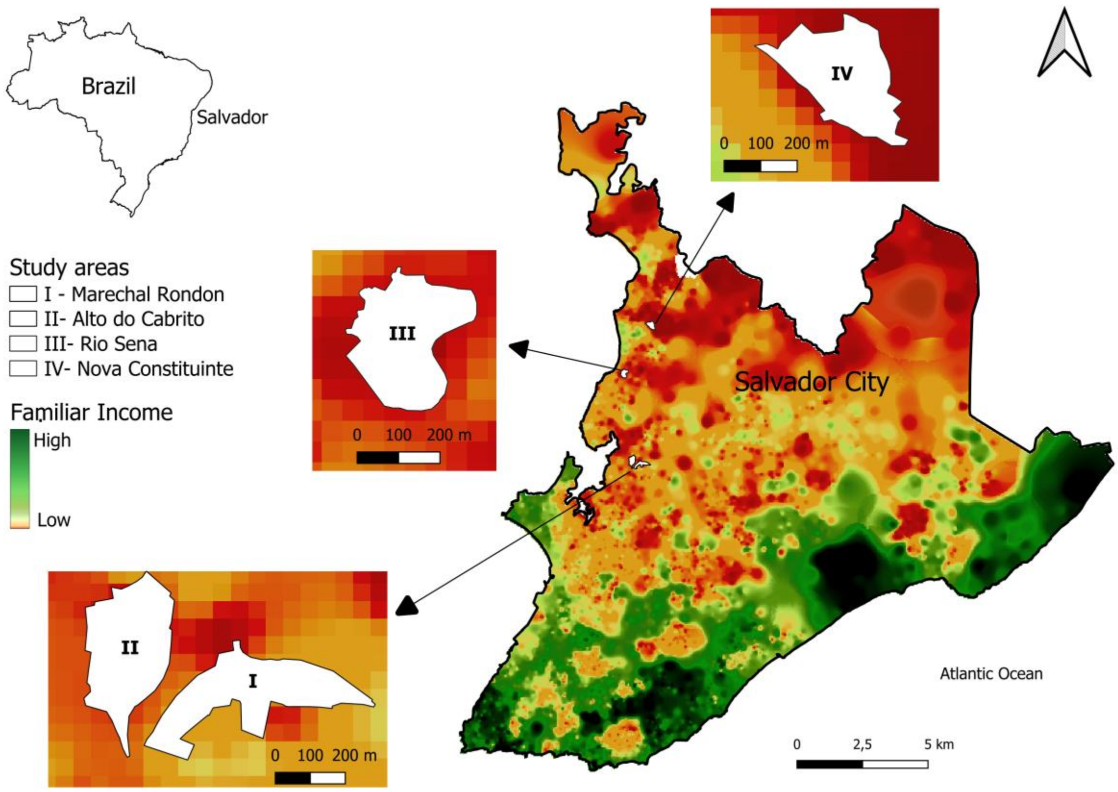


Figure 4.1 Map showing the location of the four study areas: Marechal Rondon (I), Alto do Cabrito (II), Rio Sena (III) and Nova Constituinte (IV), outlined in white in Salvador, Brazil. Distribution of family income, high (green) and low (red)

4.3.2 Serological data

A serological analysis was performed on consenting participants across all four study areas using the Microscopic Agglutination Test (MAT), as described in Khalil et al, 2021, [55] and De Oliveira et al, 2024 [74]. MAT is based on dark-field microscopy detection of serum agglutination samples from an individual with live *Leptospira* antibodies. We conducted the test with serogroups Icterohaemorrhagiae, strain Fiocruz L1-130, and Cynopteri, strain 3522C. A result was considered positive if 50% or more leptospires were agglutinated by MAT with a titre of ≥1:50.

4.3.3 Collaborative mapping

The collaborative mapping process was carried out in three phases, detailed below.

4.3.3.1 Phase 1: Recruitment of young partners

Two cultural associations from the study areas, the Emília Machado Bahia group (AEMBA) in Marechal Rondon and Centro Cultural Teatro E^2 in Alto do Cabrito, were approached to recruit young residents to be involved as research partners. These young partners were trained to take part in fieldwork and mapping activities. The criteria for recruitment included being aged between 13 and 22 and participating in the activities of local organizations. The final group of young partners had to be composed of at least 50% self-declared black or mixed-race individuals.

4.3.3.2 Phase 2: Field surveys

Teams were created to carry out field surveys. These were made up of one young local research partner, one agent from the Zoonosis Control Center (CCZ) and one university researcher with experience in spatial data collection. Targeted sampling of 244 residents across all four study areas was performed, using catalogued households from a 2018 census [55]. Individuals who were aged >18 years old, slept three nights per week within the study area, were able to provide written informed consent and were considered heads of household were asked to complete a questionnaire. These questionnaires captured the participant's environmental health risk perception and were carried out between August 2018 and March 2019.

The questionnaire asked the participant to name the main environmental risks to health that were present in the community. The participant was then asked to draw on a map of where the risks were. We used a coloured A3 map with satellite images from the Google Earth platform at a scale of 1/500 meters. The participant was first introduced to local landmarks on the map, such as their own homes and streets, to allow them to locate themselves on the image. Then, they were asked to draw the specific risks they had mentioned on the map and give them a level of risk (low, medium or high). They could draw these risks as points, lines or polygons, creating georeferenced risk perceptions. Participants could assign multiple risks to the same area they had identified on the map.

These georeferenced risk perceptions were processed using the Vicon SAGA Geographic Information System platform [75]. The young research partners digitized the perceptions drawn on the maps, creating shapefiles of each answer given by each participant.

4.3.3.3 Phase 3: Spatial analysis

The georeferenced perception data was processed to create a combined set of perceptions for each study area. Perceptions that were stored as lines or points were given a 5-meter circular buffer around them, due to spatial precision uncertainty, before being merged with polygons. These mapped perceptions were then grouped by type and level of risk perceived. Given the sparse use of all three risk categories (Table 3), low and medium perceived risk were combined into one group. This created a unique area for each type of risk perception, level of risk (high and low) and study area.

The different perceptions were then compared to objective measures of risk. Households in each of the study areas were classified into two groups: those with at least one known leptospirosis seropositive individual living there and those with none, using the serological data described above. This was used as a proxy for leptospirosis infection risk across the study areas. Rat traps and rat track plates were used as objective measures of rat risk. Traps that had caught at least one rat and track plates that were used by rats were both considered positive measures of rat presence. Matching pairs (e.g. high-risk perception and leptospirosis positive households, low risk and negative households) were compared to incongruous pairs (e.g. high risk and negative households, low risk and positive households) to create a Cohen's kappa score for agreement. To facilitate the analysis, high risk perception took precedence over low-risk perception in areas where both were present. The locations of rubbish piles were used to calculate the density of these with each type of perception polygon.

4.4 Results

4.4.1 Sociodemographic and serological characteristics

Among eligible residents of the four communities, 244 participants were included in the study. Of these, the majority were female (70.5%), with a relatively uniform distribution between the communities: AC (71.6%), MR (64.9%), NC (72.7%), and RS

(72.5%). The mean age of the participants was 46.6 years (standard deviation, SD = 15.2), varying between 44.0 years in AC (SD = 14.8) and 51.9 years in MR (SD = 16.6). The majority of participants self-declared as black (48.4%) or mixed race (39.8%), a similar composition in each of the communities (Table 4.1).

Regarding occupation, the majority of participants were unemployed (67.6%), with the highest proportion of unemployed in RS (72.5%) and the lowest in AC (59.3%). The overall employment rate was 27.5%, highest in AC (29.6%) and lowest in MR community (22.8%). The average monthly income was R$537.6 (SD = 627.7), ranging from R$406.3 (SD = 535.7) in RS to R$584.9 (SD = 638.9) in AC (Table 4.1).

Most participants in this study consented to providing blood samples (91.8%) in the serological survey. In NC, all participants provided samples (100%), followed by RS (98.0%), AC (85.2%), and MR (87.7%). Refusal to provide blood samples was 3.3% of participants (Table 4.1).

The prevalence of leptospirosis antibodies across all study areas was 12.2%. This was highest in RS, where 19.6% of participants were serologically positive for *Leptospira* antibodies, and lowest in AC with 8.6%. However, there were a number of individuals who did not consent to have their blood sample taken and for which we could not ascertain their serological status.

Errors during the data collection phase resulted in some socio-demographic characteristics not being stored appropriately. This resulted in missing data, as is reported in Table 4.1.

Table 4.1 Sociodemographic characteristics of participants in study areas

Sociodemographic characteristics	**Communities**				
	Overall	**AC**	**MR**	**NC**	**RS**
	N = 244	**N = 81**	**N = 57**	**N = 55**	**N = 51**
	Frequency (%) or Mean (SD)				
Sex					
Female	172 (70.5)	58 (71.6)	37 (64.9)	40 (72.7)	37 (72.5)
Male	72 (29.5)	23 (28.4)	20 (35.1)	15 (27.3)	14 (27.5)
Age (years)	46.6 (15.2)	44.0 (14.8)	51.9 (16.6)	47.2 (14.9)	44.1 (13.0)
Missing	1 (0.4)	1 (1.1)	0 (0.0)	0 (0.0)	0 (0.0)
Ethnicity					
White	10 (4.1)	3 (3.7)	2 (3.5)	2 (3.6)	3 (5.9)
Black	118 (48.4)	38 (46.9)	31 (54.4)	27 (49.1)	22 (43.1)
Asian	5 (2.0)	2 (2.5)	2 (3.5)	1 (1.8)	0 (0.0)
Mixed	97 (39.8)	27 (33.3)	19 (33.3)	25 (45.5)	26 (51)
Indigenous	2 (0.8)	2 (2.5)	0 (0.0)	0 (0.0)	0 (0.0)
Missing	12 (4.9)	9 (11.1)	3 (5.3)	0 (0.0)	0 (0.0)
Current employment					
Unemployed	165 (67.6)	48 (59.3)	41 (71.9)	39 (70.9)	37 (72.5)
Employed	67 (27.5)	24 (29.6)	13 (22.8)	16 (29.1)	14 (27.5)
Missing	12 (4.9)	9 (11.1)	3 (5.3)	0 (0.0)	0 (0.0)
Monthly salary (R$)	537.6 (627.7)	584.9 (638.9)	566.9 (527.6)	564.1 (765.5)	406.3 (535.7)
Missing	19 (7.8)	11 (13.6)	4 (7.0)	1 (1.8)	3 (5.8)
Blood sample					
Yes	224 (91.8)	69 (85.2)	50 (87.7)	55 (100)	50 (98.0)
No	8 (3.3)	3 (3.7)	4 (7.0)	0 (0.0)	1 (2.0)
Missing	12 (4.9)	9 (11.1)	3 (5.3)	0 (0.0)	0 (0.0)
Leptospirosis serological status					
Positive	30 (12.2)	7 (8.6)	6 (10.5)	7 (12.7)	10 (19.6)
Negative	194 (79.5)	62 (76.5)	44 (77.2)	48 (87.3)	40 (78.4)
Missing	20 (8.2)	12 (14.8)	7 (12.3)	0 (0.0)	1 (2.0)

4.4.2 Environmental characteristics

Households which provided perception data were compared to all households that were censured in the respective study areas (Table 4.2). Households sampled in the present study in AC, MR, and RS were surrounded by more vegetation (910.5 m^2 [AC], 600.2 m^2 [MR], and 1473.0 m^2 [RS]) and soil (79.6 m^2 [AC], 83.1 m^2 [MR], and 38.3 m^2 [RS]) and less impervious land (1835.6 m^2 [AC], 2130.1 m^2 [MR], and 1314.2 m^2 [RS]) compared to the community mean (vegetation: 801.7 m^2 [AC], 525.6 m^2 [MR], and 1212.4 m^2 [RS]; soil: 71.5 m^2 [AC], 86.1 m^2 [MR], and 35.8 m^2 [RS]; impervious: 1952.9 m^2 [AC], 2201.8 m^2 [MR], and 1577.4 m^2 [RS]). The opposite was seen in NC, where sample households were located in areas with more impervious land (2055.3 m^2 vs. 1885.9 m^2) than the community mean (Table 2).

Similarly, in these three study areas, the sample households were found at closer distances to sewers (172.4 m [AC], 83.0 m [MR], and 73.4 m [RS]) and lower elevations (57.2 m [AC], 48.5 m [MR], and 63.1 m [RS]) than the community mean (distance to sewer: 173.3 m [AC], 93.7 m [MR], and 74.5 m [RS]; elevation: 58.9 m [AC], 51.2 m [MR], and 66.7 m [RS]). Sample households in AC and MR were found at farther distances to rubbish piles (46.0 m [AC] and 28.9 m [MR]) compared to the community mean (41.6 m [AC] and 26.7 m [MR]), whilst those in NC and RS were closer (30.2 m [NC] and 42.2 m [RS]) compared to the community mean (34.6m [NC] and 43.0 m [RS]) (Table 4.2).

Table 4.2 Environmental characteristics of households in study areas

Environmental characteristics		Communities							
		AC		MR		NC		RS	
		All households N = 610	Sample households N = 103	All households N = 977	Sample households N = 121	All households N = 484	Sample households N = 69	All households N = 439	Sample households N = 67
		Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Land cover (m^2)*	Impervious	1952.9 (396.3)	1835.6 (421.2)	2201.8 (415.1)	2130.1 (470.2)	1885.9 (510.7)	2055.3 (413.2)	1577.4 (611.4)	1314.2 (554.0)
	Vegetation	801.7 (391.1)	910.5 (428.9)	525.6 (370.6)	600.2 (450.9)	832.9 (446.2)	706.7 (369.7)	1212.4 (607.9)	1473.0 (552.9)
	Soil	71.5 (88.4)	79.6 (90.8)	86.1 (107.0)	83.1 (92.3)	106.0 (199.5)	62.6 (157.0)	35.8 (53.5)	38.3 (59.1)
	Water	1.3 (9.0)	1.7 (10.9)	12.9 (34.3)	12.7 (30.2)	2.7 (16.4)	2.8 (14.3)	1.8 (5.2)	2.0 (5.3)
Elevation *(m above sea level)*		58.9 (10.6)	57.2 (9.9)	51.2 (9.0)	48.5 (7.8)	7.5 (4.6)	7.9 (4.6)	66.7 (15.2)	63.1 (12.7)
Distance to sewer (*m*)		173.3 (71.4)	172.4 (65.7)	93.7 (69.5)	83.0 (66.9)	123.6 (65.0)	135.5 (69.9)	74.5 (44.3)	73.4 (44.2)
Distance to rubbish piles (*m*)		41.6 (27.3)	46.0 (27.3)	26.7 (19.5)	28.9 (21.9)	34.6 (24.7)	30.2 (22.2)	43.0 (28.8)	42.2 (26.2)

**Land cover classifications are mutually exclusive and show the area, in m2, of each kind of cover within a 30m circular buffer around each household.*

4.5 Perceived environmental health risk

Most participants perceived sewage, garbage, and rats as the primary environmental health risks. In all communities, participants identified sewage as the primary high-risk health issue (AC: 33.6%, MR: 32.5%, NC: 27.5%, and RS: 39.2%, percentages of all perception polygons for each area). Garbage was the second most frequently perceived problem, as a high health risk, by participants in the communities of AC (28.1%), RS (27.5%), MR (27.2%), and NC (21.5%) (Table 4.3).

Across all study areas, a lower proportion of participants perceived leptospirosis (1.4%) as a high-risk health problem, which was also observed in the communities of MR (1.0%), NC (3.8%), and RS (2.5%). Furthermore, in AC, no participant perceived leptospirosis as a health risk problem (Table 4.3).

Additionally, there were more low risk perception polygons in NC compared to the other study areas. This was particularly true for sewage risk, where low risk for sewage made up 20% of all perception polygons for that area, compared to 1.3% in AC and RS, and 2.1 % in MR. This effect could also be seen with perception of low risk for garbage (NC = 6.25%, AC = 2.1%, MR = 3.7%, RS = 3.8%) and low risk for rats (NC = 3.8 %, AC = 0%, MR = 2.1%, RS = 1.3%) (Table 4.3).

Table 4.3 Environmental health risks, by perception polygons

Perceived risk*	Risk level	Overall	Communities			
			AC	MR	NC	RS
		N=496	N=146	N=191	N=80	N=79
		Frequency (%)†				
Leptospirosis	Low	4 (0.8)	0 (0.0)	1 (0.5)	1 (1.3)	2 (2.5)
	Medium	1 (0.2)	0 (0.0)	1 (0.5)	0 (0.0)	0 (0.0)
	High	7 (1.4)	0 (0.0)	2 (1.0)	3 (3.8)	2 (2.5)
Rat	Low	8 (1.6)	0 (0.0)	4 (2.1)	3 (3.8)	1 (1.3)
	Medium	25 (5.0)	9 (6.2)	3 (1.6)	7 (8.8)	6 (7.6)
	High	79 (15.9)	27 (18.5)	29 (15.2)	9 (11.3)	14 (17.7)
Sewage	Low	23 (4.6)	2 (1.3)	4 (2.1)	16 (20)	1 (1.3)
	Medium	42 (8.5)	11 (7.5)	14 (7.3)	5 (6.25)	12 (15.2)
	High	164 (33.1)	49 (33.6)	62 (32.5)	22 (27.5)	31 (39.2)
Garbage	Low	18 (3.6)	3 (2.1)	7 (3.7)	5 (6.25)	3 (3.8)
	Medium	46 (9.3)	21 (14.4)	16 (8.4)	5 (6.25)	4 (5.1)
	High	125 (25.2)	41 (28.1)	52 (27.2)	15 (18.75)	17 (21.5)

** Perceived risks are not mutually exclusive, some perception polygons had various risks assigned to them*

† Percentage of all perception polygons for each study area

4.5.1 Perceived and objective environmental risk

There was no agreement across all perceived environmental risk factors and leptospirosis risk (Kappa scores: -0.02 [rubbish], -0.01 [sewage], 0.02 [rat] and -0.09 [leptospirosis]; Table 4 and Fig. 2). The majority of households across all perception types fell within the leptospirosis negative and high-risk perception pairing (rubbish: 154/245, sewage: 207/314, rat: 162/257, leptospirosis: 27/52). Similarly, the pairing with the lowest count was leptospirosis positive households and low risk perception for rubbish (13/245), sewage (11/314) and rat (9/257). Positive households and high-risk perception for leptospirosis ranked the lowest for this perception group (4/25) (Table 4.4).

Table 4.4 Number of households, characterised by their Leptospira seropositivity, within each type of risk perception polygon. Corresponding Kappa score showing agreement between perceptions and infected households

	Risk Perception							
	Garbage		**Sewage**		**Rat**		**Leptospirosis**	
Household leptospirosis status	**Risk level**							
	High	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**
Positive	42	13	65	11	50	9	4	5
Negative	154	36	207	31	162	36	27	16
Kappa score	-0.02		-0.01		0.02		-0.09	
p value	0.465		0.752		0.590		0.331	

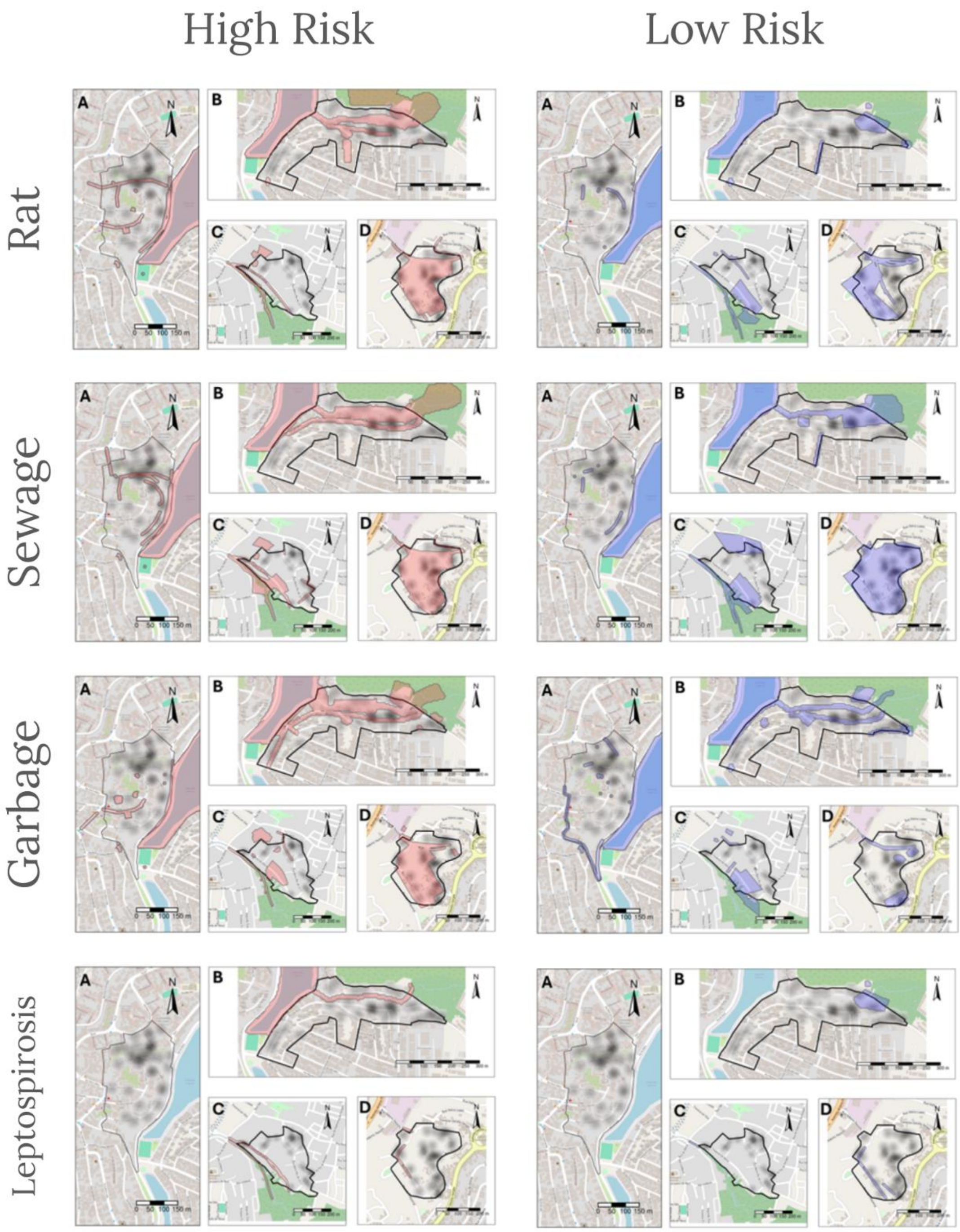


Figure 4.2 Maps showing areas of high risk perception (red, left hand side) and low risk perception (blue, right hand side) for each of the highlighted risks in each of the study areas: A) Alto do Cabrito, B) Marechal Rondon, C) Nova Constituinte and D) Rio Sena. In an effort to maintain anonymity, leptospirosis positive households are shown as a kernel density distribution denoted as a black-to-transparent graduating scale. The highest density is indicated by the darkest areas, which represent 4 households.

Comparing rat presence and rat risk perception, there was strong evidence of a slight disagreement, which was unlikely to have happened by chance (Table 4.5). The areas where people were perceiving as being high risk for rats had more negative traps and track plates across all study areas.

Table 4.5 Number of positive rat traps and track plates within each type of rat risk perception. Corresponding Kappa score

		Risk Perception Rat	
Rat Presence	**Leptospirosis status**	**High**	**Low**
	Positive	184	123
	Negative	238	71
Kappa score		-0.17	
p value		< 0.001	

Individuals were perceiving a high risk for rubbish where there were more rubbish piles. This created a higher density of rubbish piles in high-risk perception polygons than in low-risk perception polygons (Table 4.6).

Table 4.6 Rubbish pile densities within each level of rubbish risk perception polygons

Communities	**Risk Perception Rubbish**				
	Low		**High**		**Density difference (n/km2)**
	N°	**Density (n/km^2)**	**N°**	**Density (n/km^2)**	
AC	4	78.8	7	136.5	56.8
MR	2	27.2	24	260.4	233.2
NC	0	0	7	329.5	329.5
RS	1	88.2	7	162.8	74.6

4.6 Discussion

In this study, we conducted extensive collaborative mapping in four urban informal settlements in Salvador, Brazil. Residents identified sewage, garbage, and rats as the main environmental health risks. However, there was no agreement between the areas perceived as high risk and the location of leptospirosis-positive households. Similarly, there was no agreement between the areas considered low-risk and leptospirosis-negative households.

Leptospirosis has been considered a disease that primarily affects adult men [58,61], self-identified as Black (*preto* and *pardo*), living in regions located in valleys (low altitudes) with poor sewage services and infrastructure [58,61]. Vegetation and ground cover have been associated with an increased risk of contamination by *Leptospira*, and consequently, an increased risk of human infection [61]. The predominant profile of participants in our study was that of unemployed women with low income. We also found that households included in our study were surrounded by more vegetation and soil, and less impervious terrain, in addition to being closer to sewage systems and located at lower altitudes when compared to all households in the respective communities.

The population profile found in this study, despite some missing data, may have implications for the perception of environmental risks. For example, adults generally tend to have a greater identification with their place of residence compared to younger people [76]. Additionally, this population profile may suggest more concerns related to health issues in this group. Women are often more involved and engaged in community and family activities, which may contribute to increasing their sensitivity and perception of environmental health risks in their context [69]. Furthermore, our sample was broadly similar to previous studies with regards to leptospirosis prevalence. An important outlier was the prevalence of our sample in RS, which was 19.8%, compared to 12% estimated in a previous study [55]. The issues we encountered with the missing data could have affected these calculations and biased our final results.

Although we did not identify previous studies addressing the contribution of race/colour to the perception of environmental health risk, it is important to consider the racial and socioeconomic inequalities experienced strongly by this population segment. Communities predominantly composed of Black populations, as in our study, are exposed to more environmental health risks, as they are historically subject to areas with inadequate housing conditions and more limited access to basic services [55,60]. This aspect can influence both their perception of risk and their actual exposure to diseases like leptospirosis. Additionally, these populations generally have fewer material resources, and the conditions they live in increase their vulnerability to diseases.

The environmental characteristics of vulnerable communities also play a crucial role in exposure to risks that can cause leptospirosis. In this study, we found that residences located in the AC, MR, and RS communities were surrounded by more vegetation and soil, but less impermeable terrain compared to the community average. These areas may, therefore, offer a more favourable environment for the presence of rodents. This in turn could lead to increased contact with soil contaminated with urine from these hosts [58,61]. In contrast, the NC community presented a higher amount of impermeable terrain, which can significantly reduce exposure to contaminated soil and contact with *Leptospira*, especially during rainy periods. This could explain why perceptions in the NC community tend to be of low risks for the different factors. We also found that households in our study were closer to sewage and garbage points than the community average. Residences near sewage and garbage are generally at greater risk of exposure to pathogens, including the *Leptospira* bacterium [58,61]. Residents' perceptions of these risks are, therefore, consistent with their reality, as many identified these factors as the main environmental health risks in their context.

Studies conducted in peripheral communities of Salvador identified the domestic rat as the main reservoir for *Leptospira* transmission [61]. Additionally, rats sighted by residents were correlated with the risk of acquiring antibodies against *Leptospira* in a previous study [61]. We found that residents understand the risks that rats pose, as they perceive them as a risk across all study areas. However, we found that there were more positive rat traps and track plates in areas where residents thought the risk of rat presence was low. Resident do correctly identify where rubbish piles accumulate—a more obvious risk, given the visual impact.

We also found a low perception of leptospirosis as a health risk. This is highlighted in the study area AC, where no participant identified leptospirosis as a health risk of any level. This suggests the need for health education actions addressing the modes of disease transmission. This is corroborated by a knowledge, attitudes and practices study performed in the MR community, where it was identified that residents presented some gaps regarding the mode of leptospirosis transmission [77]. Our findings indicate that some factors associated to leptospirosis transmission are of greater concern to community residents than other factors and the disease itself. This could be due to the nature of these factors. In other words, residents are more aware of where rubbish accumulates given the visual impact but are not as clear where rats are present.

Future collaborative mapping studies should be concerned with the accuracy of data collection and explore in more detail the relationship between specific sociodemographic and environmental characteristics and their influence on the perception of environmental health risk. Additionally, there may be differences in the perception of environmental health risk according to the place of residence and proximity to risk in the communities where our study was conducted, which can be explored in other works. Furthermore, new studies should also focus on more effective strategies for interacting with public agencies and Geographic Information Systems (GIS) technologies that are more accessible and user-friendly to the community. This could increase the use, engagement, and sustainability of collaborative mapping processes facilitated by public agencies, reducing the consultation need for mediation by university groups. Gamification initiatives, such as the +Lugar platform [78,79] are being developed in this regard. In addition, research that evaluates the impact of interventions resulting from these collaborative processes on the communities involved is essential. Such research could investigate aspects such as the population of synanthropes in the environment, human health, and social control.

Although violence is not addressed in detail in this article, it represented a significant challenge for the study. Access to certain areas of the communities was restricted at times, which not only prevented mapping activities on those days but also hindered the participation of young partners in some planning meetings, as their movement on those days was curtailed. These restrictions did not impact the comprehensiveness of the collected data but affected the duration of some stages of the collaborative mapping process.

It is also important to highlight the positive effect of recruiting local young partners to be involved with the research. The participation of young partners not only increased the quality and relevance of the collected data but also promoted greater engagement and acceptance of the research by local communities. The direct involvement of young partners in the co-design process of field instruments and field research was fundamental to the success of the collaborative mapping. We recommend applying similar engagement practices in future community research projects.

Our study has limitations. The first is the cross-sectional design adopted, which does not allow for inferences of cause-and-effect relationships or testing of causal hypotheses. In addition, the presence of missing data for some study variables may have underestimated our findings. We also recognise that the work carried out using perceptions could be complemented by other qualitative techniques, such as focus groups or semi-structured interviews. An integrated qualitative-quantitative approach, using these techniques alongside spatial methods of analysis, could help us understand more deeply the issues not captured in this study. Despite these limitations, this was one of the few studies, if not the first, to simultaneously assess the perception of environmental health risks through collaborative mapping, in four peripheral communities of Salvador, Brazil, with the support of young partners from these communities.

4.6.1 Conclusion

In the current century, efforts to identify more effective and sustainable interventions for urban leptospirosis in vulnerable areas have been hampered by the lack of community involvement and participation in research and the production of information on environmental health risks. It is essential to prioritize the inclusion of communities in these contexts to ensure the relevance and applicability of proposed interventions, as well as their alignment with local priorities. We present a robust method to capture individual's perceptions of environmental health risks, focused on participatory research and collaborating with local youth partners. This presents an important method to involve communities in interventions affecting their health and wellbeing.

4.7 Ethics approval and consent to participate

This study was approved by the Research Ethics Committee of the Collective Health Institute/ Federal University of Bahia (CEP/ISC/UFBA), with CAAE number 68887417.9.0000.5030, and by the National Research Ethics Committee (CONEP) linked to the Brazilian Ministry of the Health under approval numbers 2.245.914–2.245.914.17–3.315.568. Informed consent was obtained from all participants and/or their legal guardian/s.

4.8 Acknowledgements

We sincerely thank all the residents and community leaders of Marechal Rondon, Alto do Cabrito, Nova Constituinte, and Rio Sena. We also want to thank you for participating and trusting our research team. With everyone's collaboration and active involvement, this study was possible. To our research colleagues and field staff, our sincere thanks throughout all stages of the study. The work and collaboration of each of you were essential for collecting data and analysing the information in this manuscript.

4.9 Supplementary material I

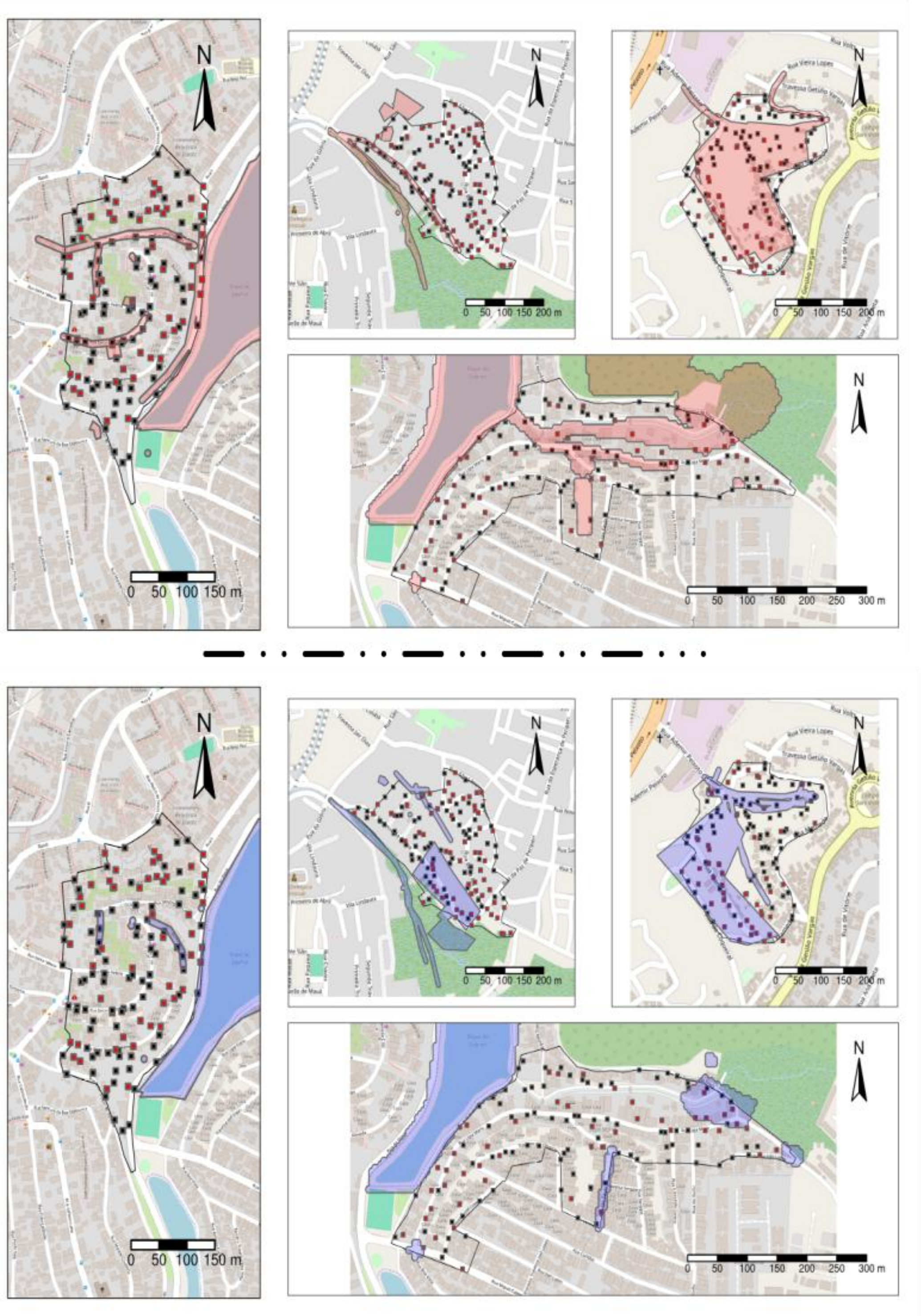


Figure 4.3 Locations of rat traps and track plates (red: positive, black: negative) with respect to areas perceived as high risk (red, top panel) and low risk (blue, bottom panel) for rat presence

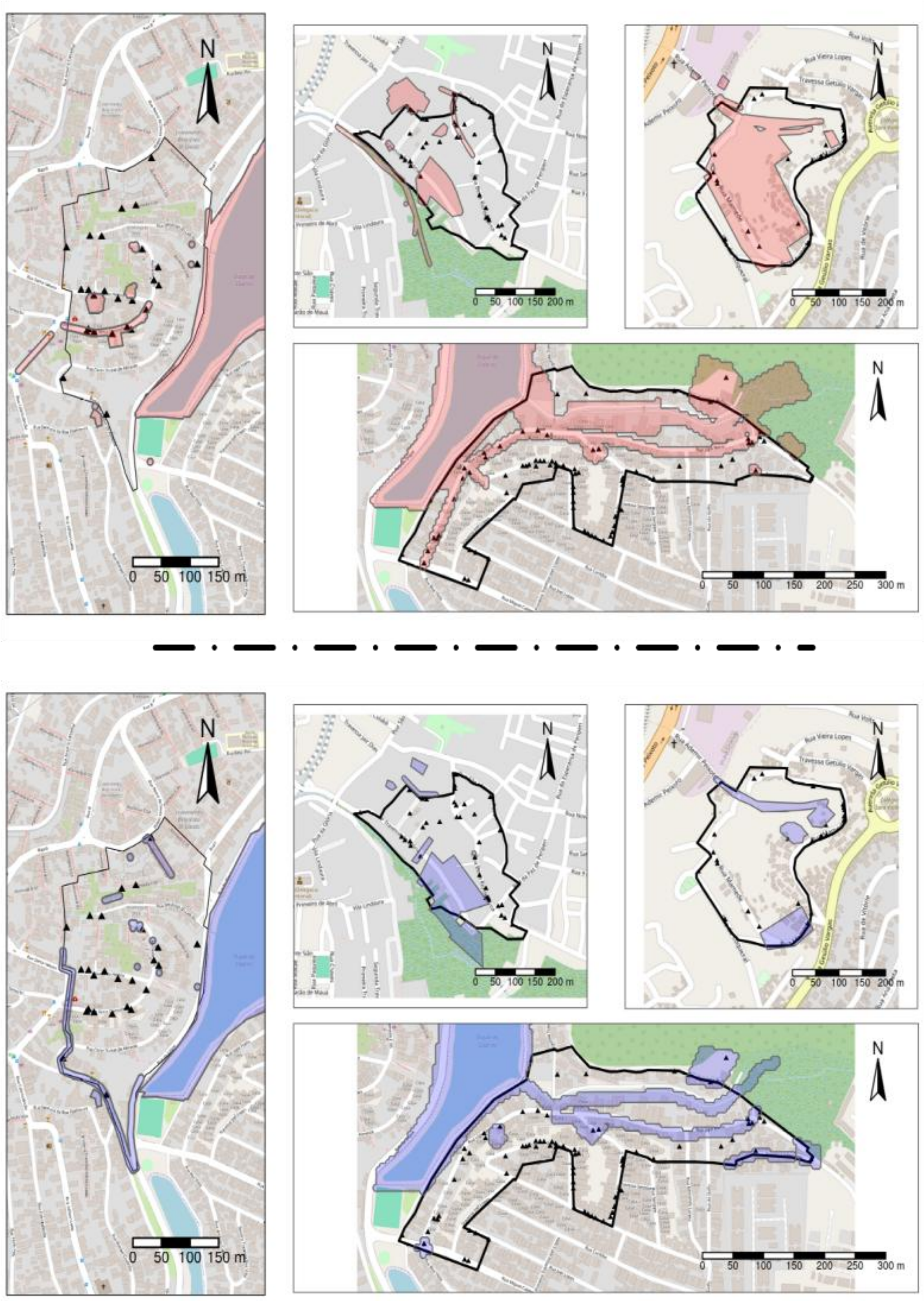


Figure 4.4 Locations of rubbish piles (black triangles) with respect to areas perceived as high risk (red, top panel) and low risk (blue, bottom panel) for rubbish

4.10 Supplementary material II

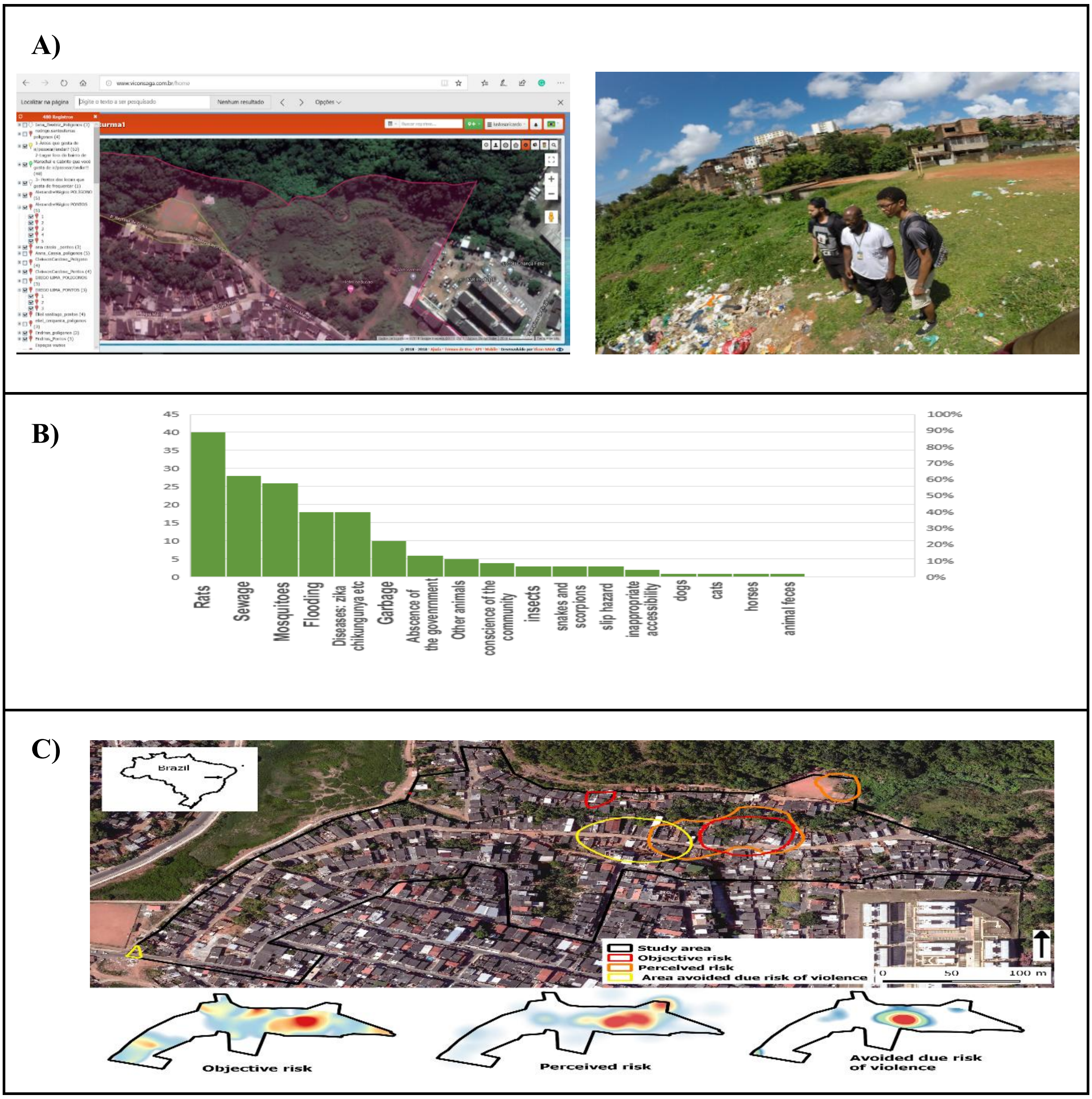


Figure 4.5 Panel showing results presented to communities and public bodies: A) WebMap environment in vicon SAGA showing the specific location of problems indicated by residents; (B) Graphic with categories of problems identified as health risks in the neighbourhood; (C) Map of concentration of places indicated as health risks, of people with positive serology for leptospirosis and of places indicated as violent in the neighbourhood

After the collaborative mapping stages, graphics, web maps, and thematic maps relating to the results of the collaborative mapping were produced. These materials were prepared in an accessible language to communicate with the population and public agencies to disseminate the findings, promote discussions in the associations involved, and raise awareness among institutional partners. This approach aimed to bring public agencies closer to the communities, create job opportunities for young people, and encourage necessary interventions. The meetings with public agencies focused on social areas, urban maintenance and cleaning, technology, and urban furniture.

The ViconSAGA [75] platform was used to create the WebMap. The young people actively participated in the process, digitizing points, lines, and polygons indicated by residents during the On-field survey phase of the collaborative mapping. These elements were identified as posing a health risk in the neighbourhoods, and descriptions of these elements and photos were included. The platform allows any user registered in the web project to access this information for consultation.

In addition to the web map, the research team produced a Kernel Concentration Map, which maps locations indicated as presenting a health risk (subjective risk) and the distribution of people with positive serology for leptospirosis (objective risk). The points and centroids of polygons and lines indicated as presenting a health risk were processed to produce the Kernel map related to the concentration of locations indicated as presenting a health risk. These elements were weighted according to the level of risk attributed by the participants (1 to 3) and with a radius of 50 meters. The Kernel concentration of people with positive serology for leptospirosis was generated from the points of the households, considering the number of positive people as a weight and using a radius of 50 meters. In addition, the points indicated by the young people as presenting violence were processed to generate a Kernel concentration, also with a radius of 50 meters. Subsequently, we created a summary map that integrated the previously described Kernel concentration analyses and the overlapping polygons of locations of objective risk for leptospirosis, subjective risk, and violence. The polygons were created from the last quartile of isolines of the Kernel analyses. In addition to these maps, graphics were produced with the subjective risk categories indicated by residents for each neighbourhood. The thematic maps and graphs were created, respectively, in Qgis 2.18 and Excel software.

4.10.1 Details about the phase sharing with communities and public service provider

The public companies in the city of Salvador visited promoted several educational and social interventions in the communities studied (Figure 4.5). Among the actions, the following stand out: preparing young people for university entrance exams, artistic interventions with graffiti, implementing a community garden, and creating job opportunities for two young people from the community in public companies. One of these young people reached the position of advisor of the Urban Development Company (DESAL), acting as the project coordinator at the institution. In addition, garbage was removed from a chronic accumulation site, where years of useless waste had been deposited by the population, and a collection box was installed in one of the four participating neighbourhoods. Furthermore, the participation of young people in public consultations influenced the inclusion of objectives in the Innovation Law of the city of Salvador, prioritizing actions for black men and women from informal neighbourhoods. It was observed, however, that only young people, associations, and communities from two of the four neighbourhoods involved were included in actions in partnership with public bodies after the collaborative mapping activities.

Chapter 5 Collaborative Mapping as a methodology for identifying community perceptions on basic sanitation needs and interventions for leptospirosis in Salvador, Brazil

Fabiana Almerinda G. Palma[1¶], **Pablo Ruiz Cuenca[2¶],** Daiana de Oliveira[1,3], Ana Maria N. Silva[4], Yeimi Alexandra Alzate Lòpez[1], Diogo César de C. Santiago[5], Marbrisa N. R. das Virgens[6], Ariane Sousa do Carmo[7], Antonia dos Reis[8], Gislane de Jesus do Carmo[1], Andrea Maria Lima[1], Renata Santos Almeida[1], Lucineide Oliva[1], Juliet O. Santana[3,9], Pedro Maciel[10], Tania Bourouphael[12], Emanuele Giorgi[2], Ricardo Lustosa[11], Max T. Eyre[12], Caio G. Zeppelini[1,13], Cleber Cremonese[1], Federico Costa[1,3¶*]

[¶] These authors contributed equally to this work.

[1]Institute of Collective Health, Federal University of Bahia, Canela, Salvador, Bahia, 40110-040, Brazil.

[2]Centre for Health Informatics, Computing and Statistics (CHICAS), Lancaster Medical School, Lancaster University, United Kingdom;

[3]Instituto Gonçalo Moniz, Fundação Oswaldo Cruz, Ministério da Saúde, Rua Waldemar Falcão, 121, Salvador, Bahia, Brazil;

[4]University of Bristol, Bristol, United Kingdom;

[5]Departamento de Medicina Preventiva e Social, Faculdade de Medicina da Bahia, Federal University of Bahia, Salvador, Bahia, Brazil;

[6]Escola Politécnica, Programa de Pós-Graduação em Engenharia Civil, Federal University of Bahia, Salvador 40210-630, Bahia, Brazil;

[7]Universidade Salvador, Salvador, Bahia, Brazil;

[8]Centro Universitário Cidade Verde, Salvador, Bahia, Brazil;

[9]Institute of Geosciences, Federal University of Bahia, Salvador, Bahia, Brazil;

[10]Federal University of Bahia, Salvador, Bahia, Brazil;

[11]Federal University of Western Bahia - Campus Barra, Bahia, Brazil

[12] London School of Hygiene and Tropical Medicine, London, UK

[13]Department of Wildlife, Fish and the Environment, Swedish University of Agricultural Sciences, Umeå, Sweden.

5.1 Abstract

Despite the relevance of spatial mapping in analysing the health situation and understanding the risk factors and determinants of leptospirosis, peripheral urban communities often remain invisible on maps, which tend to use data and methods that do not express community contribution nor promote local participation. Furthermore, in the implementation of sanitation interventions, the same happens: there is limited user participation, and a lack of identification of intervention needs based on the perception of community residents, failing the interventions. We conducted a cross-sectional study through collaborative mapping from February to October 2022 with 213 residents and self-declared heads-of-household in two peripheral urban communities. We analysed the perception of sanitation needs indicated by residents and their relationship with the risk of leptospirosis in these communities. Based on community perception, sewage (NS: 87.1%; JSI/ME: 84.9%) and urban cleaning and solid waste management (NS: 25.9%; JSI/ME: 32.6%) were the sanitation needs. In NS, most participants indicated that the necessary interventions for sewage improvement were actions of sewer cleaning and sealing (26.5%), sewer cleaning and piping (23.5%), and implementation/installation/construction of a sanitary sewage network (41.4%). In JSI/ME, interventions included sewage sealing (48.7%) and piping (25.6%), in addition to actions to maintain sewage cleaning (93.3%). The removal of solid waste (trash) in the square (NS: 22.2%) and on the streets (JSI/ME: 69.2%), as well as community awareness (JSI/ME: 15.4%), were indicated as interventions to meet the needs of urban cleaning and solid waste management. Respondents agreed on where interventions should occur, which congregated around the local river. We found a negative correlation between the predicted leptospirosis seropositivity and perceived intervention needs in both study areas. The prevention of diseases such as leptospirosis in peripheral urban communities requires integrated basic sanitation interventions, encompassing different components and aligned with the local needs perceived by residents.

Keywords: *Leptospira*; Community-based participatory research; Basic Sanitation; Diagnosis of Health Situation; Zoonosis

5.2 Introduction

In low-and middle-income countries (LMICs), zoonotic diseases remain a public health problem. Among these diseases, urban leptospirosis affects populations in situations of greater social vulnerability, who reside in territories with precarious sanitation and infrastructure conditions [41,56,80–82]. Leptospirosis is a neglected disease [56] caused by pathogenic spirochete bacteria of the genus *Leptospira* [81,82]. Its main reservoir in urban areas is *Rattus norvegicus*, which sheds pathogenic leptospires into the environment through urine [83,84].

Knowledge of the environment favours the understanding of the distribution of leptospirosis, the living conditions of people[85], as well as the main determinants of disease[58,61]. Furthermore, it is an essential resource for identifying the unequal impact of the main risk factors that contribute to the maintenance of these diseases in socially vulnerable contexts[58]. This knowledge also makes it possible to identify determinants, such as sanitation, which play a crucial role in maintaining leptospirosis[55].

The use of participatory methodologies, such as collaborative mapping, for environmental knowledge of leptospirosis facilitates the identification of determinants of and risks to health, allowing the proposal of more effective interventions to prevent these risks[67]. This methodology can favour the implementation of timely interventions and ensure greater sustainability of actions through the participation of communities, especially in areas marked by extreme vulnerabilities and historical, environmental and social inequalities[86,87].

Collaborative mapping is a map creation process in which the population voluntarily contributes by generating relevant content[88], actively participating in the process of recognizing the territory in which they live[89] through the use of integrated methods and technologies[90]. This approach is considered a valuable instrument for popular participation[91], as it allows local social actors to fill gaps in official maps[92], build a solid understanding of the resources, health problems, risk factors and determinants of the diseases that affect them[65]. In addition, it promotes the identification of future interventions aimed at reducing or eliminating problems that pose a risk to life.

Diagnosing health risks and determinants through special analyses that use participatory methodologies is essential in analysing the health situation. It is a key factor in understanding the necessary interventions, especially in places with absent or insufficient basic sanitation services, such as sewage and urban cleaning[59]. In contexts with problems related to sewage, a determinant of leptospirosis, it is common to observe limited community participation in supporting the construction of projects and the management of construction. Community participation is often limited to specific agreements allowing pipes to pass through private properties[93], which may be one of the factors contributing to the persistence of local problems related to these services.

Although there are official maps containing information on risk factors and determinants in territories that suffer from vulnerability processes[94], some areas of these environments often remain invisible or do not have updated information on the maps[95]. Existing maps lack adequate information on hard-to-reach areas[96] and predominantly use techniques that do not encourage community participation. Traditional mapping tools and techniques such as Geographic Information Systems (GIS) and geomorphological mapping[97] are not capable of meeting the needs of local communities due to their objectives and scales. Furthermore, excessive control and lack of communication between public agencies responsible for collecting data and generating information often result in the lack of spatial data related to infrastructure and socioeconomic conditions at the municipal level[9797].

The lack of detailed information about the community in urban environments hinders responses to public health emergencies and disasters[96], as well as a broader understanding of risk factors and determinants of health. It also restricts the planning of interventions to priority areas, as perceived by communities. This issue is particularly relevant in interventions related to sanitation[96] and the prevention of diseases such as leptospirosis, which continue to affect populations in low-income communities in large urban centres. Previous studies have reported that poor environmental and sanitation conditions increase the risk of diseases such as leptospirosis[55,58,61]. However, few studies have analysed residents' perceptions of the need for sanitation and the solutions and interventions suggested by those living in contexts with these deficiencies. In this study, our objective is to collaboratively identify the need for interventions in basic sanitation as perceived by residents, their spatial distribution, and their relationship with leptospirosis seropositivity in two communities where sanitation interventions were implemented.

5.3 Materials and Methods

This study is a cross-sectional study that is part of a participatory research project, which integrates space components on spatial community diagnosis of vulnerabilities associated with sanitation to improve health and reduce health disparities. The initial research was conceptualized as an expansion of the objectives of a previous study[98] aimed to analyse the perception of environmental health risks through collaborative mapping, focusing on the factors contributing to leptospirosis in four peripheral communities of Salvador, Brazil. This study was carried out by the research group and through a collaboration between people from the communities and academic researchers with study experience using collaborative mapping in similar communities. Thus, the core research team comprised community researchers (people who lived in the communities at different sites where the study was conducted) and academic researchers. These acted as supporters of the communities' residents and contributed to field research and data analysis.

5.3.1 Study Area

This study was part of a research project on health intervention and prevention of urban leptospirosis, which was started in 2021 in communities in Salvador, Brazil[99]. In these communities, we carried out a baseline serological survey with the application of individual and household questionnaires, and collection of biological samples collected by trained phlebotomists. In addition, we conducted community engagement in two areas for the involvement and participation of residents in research project activities[99].

This study integrates one of the components of the community engagement model from the research project, collaborative mapping, which enabled extensive spatial data collection in the communities. The study was carried out in the neighborhoods of Nova Sussuarana (NS) and Jardim Santo Inácio/Mata Escura (JSI/ME). These neighbourhoods are located in the periphery of the city Salvador[100], Brazil (Figure 5.1), and have a population which is mostly low-income, self-declared black, and with sanitation problems[55,60]. Unadjusted seroprevalence for *Leptospira* in NS and JSI/ME in the baseline survey was 9.0% (n= 338) and 8.0% (n= 205), respectively.

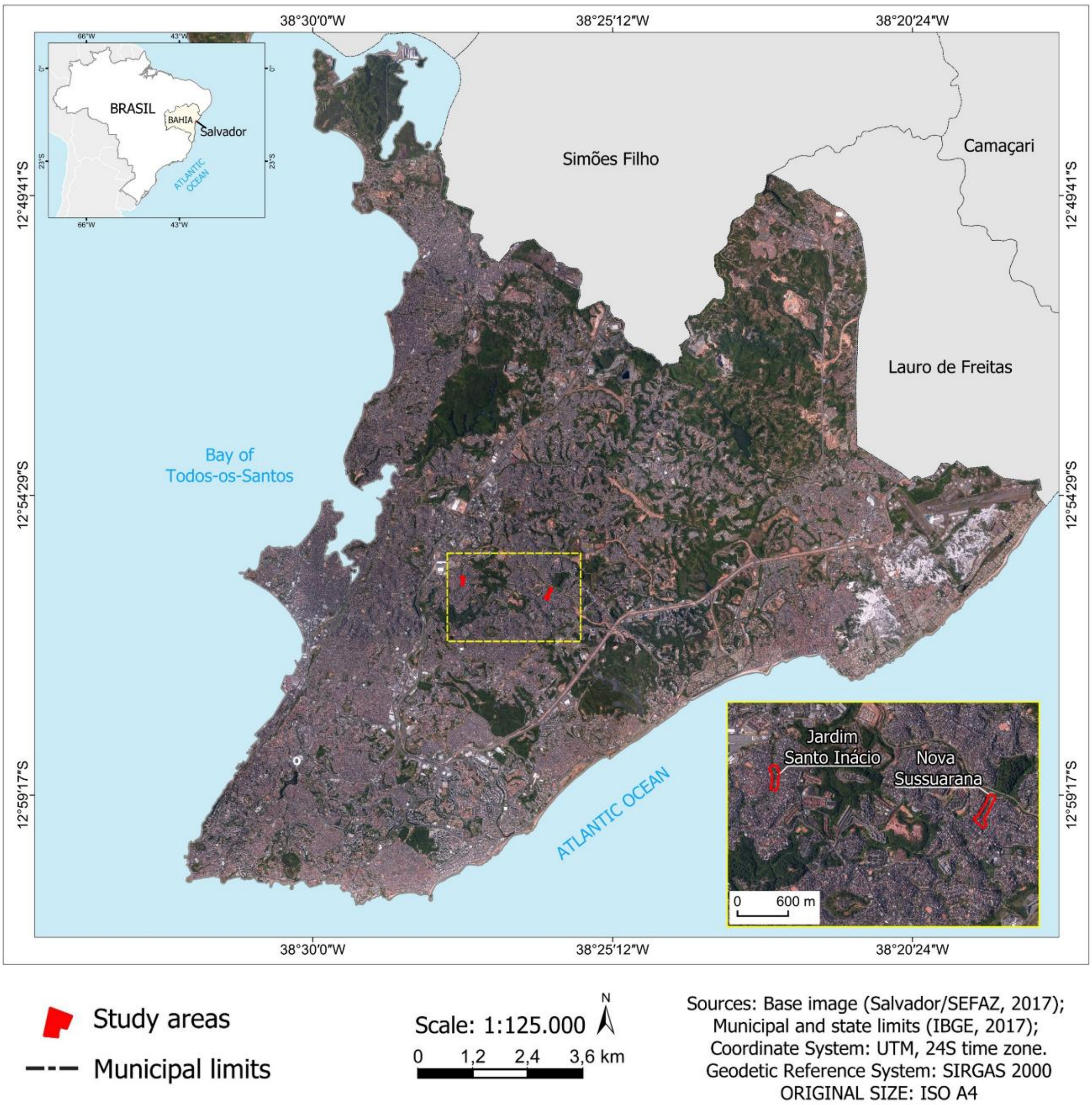


Figure 5.1 . Map of the two study areas within the city of Salvador. The authors created the figures using the results generated from the analysis of their primary data.

5.3.2 Study population

In this study, we used a census sample from the serological survey carried out in the study areas and approached those eligible to participate in this collaborative mapping study in NS (N=124) and JSI/ME (N=121). Eligible residents were (1) men and women self-declared heads-of-household (if these were absent after three consecutive home visits by the team, any family member aged 18 or older); (2) who slept in the household for at least three nights per week; (3) had participated in the serological survey in 2021; and (4) were able to provide written informed consent.

5.3.3 Data collection

5.3.3.1 Collaborative mapping

In our study, people who live in the communities were involved in all phases of the collaborative mapping, and the research process itself had a goal of social action related to using the study results to claim improvements in sanitation and infrastructure in their communities. Members of the research team and residents of Nova Sussuarana (NS) and Jardim Santo Inácio/Mata Escura (JSI/ME) participated in virtual and face-to-face training.

Due to the COVID-19 pandemic, the virtual meeting was planned for a maximum total of 10 team members, where eight were residents of the communities that actively participated in the construction of the training proposal, and the following topics were worked on: 1) Collaborative mapping: concepts, methodology, and results of the previous research project; 2) Dialogued exposition about a territorial reading of the city of Salvador and its socio-spatial segregation; 3) Social determinants of health and zoonosis; 4) Maps: definitions and uses, and location of the study area; 5) Manipulation of web map projects in the Vicon Saga system[75]; 6) Data migration from physical maps to QGIS and its processing.

After the training, the team visited participating residents between February and March 2022, for those in NS and between August and October for JSI/ME, and explained the research objectives before inviting them to participate. The team used a standardized questionnaire to capture the participants' perceptions of basic sanitation needs, what potential solutions they would recommend, and where these should be implemented, giving them sufficient time to consider their answers. At this stage, resident participation occurred at the individual consultation level. This questionnaire was validated in a previous study carried out in a community with similar characteristics to those included in this study which is awaiting publication. The research team used printed maps to help participants locate themselves, highlighting local landmarks. The participants were then able to draw their perceptions on a separate map. Data on the type of basic sanitation that required intervention were based on the classification proposed in Brazilian Law for sanitation[101].

At the same time, we classified the data on the types of intervention for basic sanitation reported by the participants into the following dimensions: implementation/installation/construction, maintenance, removal, integrated action, and others. These were based on free text answers given by participants. Implementation/installation/construction interventions corresponded to works that had not been carried out previously in the communities. Interventions classified as maintenance corresponded to improvements, suggested by participants, in sanitation works carried out in the past. Removal interventions involved removing garbage from specific locations in the communities. Those classified as integrated actions corresponded to reported interventions that comprised more than one of the mentioned components of basic sanitation. For this study, we considered river and sewage as synonymous and garbage basket and garbage containers are treated as having the same meaning as informed by participants during the research. In the case of sewage, due to the pollution of water bodies by domestic garbage and the deficiencies in the sewage system, residents began to perceive the river as part of an open sewer.

Our questionnaire was organized into six parts: 1) Health risk indicated by residents (open field variable) and the level of risk for the problem indicated (Low/Medium/High); 2) Coverage of primary care health services; 3) Indication of the health risk for the resident on the map; 4) Health promotion locations in the neighbourhood (the type of location and indication on the map); 5) Intervention and perception on basic sanitation; 6) Use of cell phones by residents: Do you have a cell phone (Yes/No); Type of cell phone (Smartphone/Basic cell phone).

For this study, we worked with questions regarding the perception of basic sanitation needs and the types of interventions suggested by the participants. Here, the variables that worked on the perception of basic sanitation were: "Need for intervention close to the residence (yes/no)," "Type of basic sanitation intervention (water supply, sewage, urban cleaning and solid waste management, urban drainage and rainwater management, others)"; "The type of intervention to solve the problem (open question)," which was categorized into five dimensions: implementation/installation/construction; maintenance; removal; integrated action; others.

Given the number of pieces of information that could be identified on the physical map regarding the sanitation intervention indication, the field team used a code and the following strategy presented in data collection: recording points, lines, or polygons which residents used to indicate the need for carrying out interventions on the components of sanitation, with the letters representing the initials of the components in Portuguese: i) sewage (E); ii) water supply (AA); urban cleaning and management of solid waste (LU); iii) urban drainage and stormwater management (D); iv) others. In this study, the "ID Vértice" served as an identification key for each problem/phenomenon indicated by the resident, which was represented through the georeferencing of geometric primitives (point, line, and polygon), using GIS for creating maps. At this stage, resident participation occurred by systematizing data on the map and discussing results in collective meetings.

The maps in A4 format were prepared to facilitate visualization by the residents during data collection. Each printed map also had a space for filling in the identification number given by the project for the household and a small caption containing the numbers related to each item identified on the maps.

5.3.3.2 Serological data

Serological data to identify previous exposure to *Leptospira* was collected by trained phlebotomists after written participant consent. Serological analyses were conducted using the Microscopic Agglutination Test (MAT), as described in Khalil et al., 2021, [55] and De Oliveira et al., 2024 [74]. The Microscopic Agglutination Test (MAT) is the gold-standard diagnostic method for leptospirosis [102]. We used a diagnostic panel that included the most prevalent serovars in the region as well as other known pathogenic serovars. These were *L. kirschneri* serovar Cynopteri strain 3522C, *L. kirschneri* serovar Grippothyphosa strain Duyster, *L. interrogans* serovar Canicola strain H. Ultrech, *L. interrogans* serovar Autumnlais strain Akiyami A, *L. borgspetersenii* serovar Ballum strain MUS 127, *L. interrogans* serovar Copenhageni strain Fiocruz L1-130 and *L. interrogans* serovar Copenhageni strain Fiocruz LV3954. Seropositivity was defined as ≥50% agglutination of leptospires at a titre of ≥1:50. Samples reactive at a 1:100 dilution were further titrated in serial dilutions. The presumptive infecting serogroup was considered the one with the highest titre, at least one dilution above the others; . Titres <1:50 were considered negative [55].

5.3.4 [102]Statistical analysis

Descriptive analyses were carried out to show differences within and between study areas, using STATA Statistical Software version 14 [103]. To assess sociodemographic, household, peri-domiciliary, and perceived sanitation needs variables, see Table 5.1, Table 5.2, Table 5.3 and Supplementary Material I: Descriptive Tables.

5.3.4.1 Seropositivity model

To assess the correlation between leptospirosis seropositivity, used as a proxy for leptospirosis risk, and perceived intervention needs, we used a logistic regression model to predict seropositivity across each study area. These analyses were carried out in R, version 4.2.1 [38]. For this, we used individual level data—including the serological data described above—from residents across both study areas. Individuals had to be living in one of the study areas for at least the last 6 months, sleep there at least 3 nights a week, be at least 18 years old and be able to provide written consent. Each individual also answered a questionnaire that collected their age and gender, amongst other characteristics. We also recorded the location of their households.

A team of researchers visited the study areas to record the locations of a number of spatial features, including known and possible risk factors (see Supplementary Material II: Leptospirosis seropositivity model and Supplementary Material IV: GAM plots). Minimum Euclidean distances from individuals' households and each of these features were calculated. Alongside these features, we created a land cover raster of each study area using satellite images taken by WorldView-3, with a resolution of 0.3 meters. These rasters had three mutually exclusive land cover classes: soil, vegetation and impervious land. A 20-meter circular buffer was created around each household to calculate the percentage of each land cover class within this area. In the analysis, each individual was linked to their household's data.

To create the logistic regression model, we started by exploring the associations between all these spatial variables and individual leptospirosis serological status, as a binary variable. We used a binomial generalised additive model (GAM) for the exploratory phase [104]], which included age, gender and study area as a priori variables [58]]. These models gave us the possibility to assess whether the variables should be included as linear or non-linear relationships. Multi-variable models were built using the Akaike Information Criterion (AIC), selecting the lowest value. Variables were grouped by themes, such as land cover or roads (see Variable selection for full list of groups). Priority was given to models where a whole group was removed. More detailed information is available in the Supplementary Material II: Leptospirosis seropositivity model.

The final model included the distance from households to pruning rubbish piles, the percentage of soil land cover within a 20-meter circular buffer—as a non-linear relationship with a knot at 25%—and the *a priori* variables mentioned above (age, gender and study area). Model coefficients were applied across raster values for these variables, keeping age and gender fixed as 35 year old male, to predict the probability of leptospirosis seropositivity for every cell in a predictive raster. The demographic characteristics had to be maintained constant to create static layers for maps. We chose these specific characteristics as they are considered the highest at-risk group for leptospirosis infection.

5.3.4.2 Perceptions vs. predictions

The perception data were available as georeferenced vector data, in either point, line or polygon form. To standardise the data, all points and lines were given a 5-meter buffer to create polygons. A grid with a resolution of 5 meters was laid over each study area. For all points on the grid, the density of each kind of perceived intervention need was calculated, using the perception polygons. As there was only one polygon for perceived intervention on water supply, this was excluded from further analyses. The predicted leptospirosis seropositivity was also extracted for each of these points (Figure 5.2).

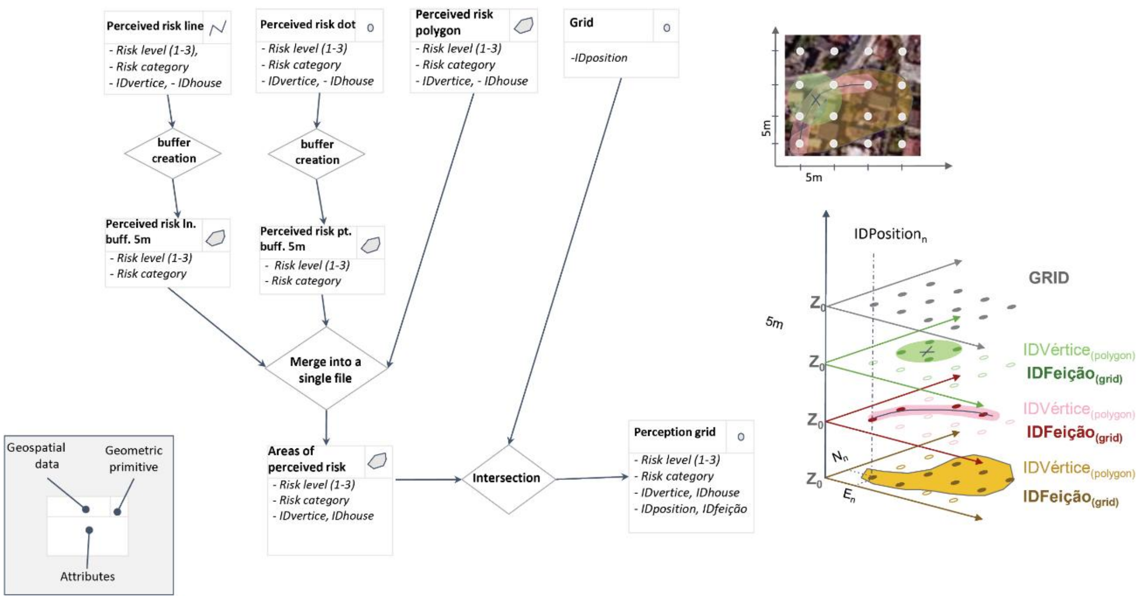


Figure 5.2 Diagram to show how perception data was standardised into a grid

A Poisson regression model was fitted to the predicted leptospirosis seropositivity and the densities of perceived intervention need, both of which had values for each grid point in the studies areas. The model estimated how predicted seropositivity—the exploratory variable—increases the rate (or density) of perceived intervention need identified by the participating residents—the response variable. Here, model coefficients quantified the associations between objective values (predicted seropositivity) and perceived values (perceived intervention need). A separate model was used for each of the intervention needs: drainage, sewage system and urban cleaning.

Given that we had the individual characteristics of the participants who supplied perception data, we were also able to perform a subgroup analysis looking at how these effects changed with gender and leptospirosis serological status.

5.3.5 Ethics Statement

This study was approved by the Research Ethics Committee of the Institute of Collective Health/Federal University of Bahia (CEP/ISC/UFBA) with CAAE number 32361820.7.0000.5030, and a National Research Ethics Committee (CONEP) linked to Brazilian Ministry of Health under approval number 4.235.251.

5.4 Results

5.4.1 Sociodemographic characteristics

Among 245 eligible residents from the communities (NS= 124; JSI/ME= 121), 213 (86.9%) were enrolled in this study (NS= 107, 50.5%; JSI/ME= 106, 49.5%), with a response rate greater than 80% in each of the communities. There was homogeneity for most of the participants' sociodemographic characteristics in the study communities, except for receipt of government assistance. Most participants who received government assistance, Bolsa Família or Benefício de Prestação Continuada, lived in NS compared to JSI/ME (44.8% vs. 3.8%; p-value= <0.001) (Table 5.1).

Table 5.1 Sociodemographic characteristics of the study population

Variables	**Responses**	**Overall (N= 212)**	**Communities**		**p-value**
			NS* (N=107)	**JSI/ME** (N= 105)**	
		Frequency (%)			
Sex	212				0.595***
Female		154 (72.6)	76 (71.0)	78 (74.3)	
Male		58 (27.4)	31 (29.0)	27 (25.7)	
Age (years)	211		**N= 106**	**N= 105**	0.732***
≤ 40		109 (51.7)	56 (52.8)	53 (50.5)	
> 40		102 (48.3)	50 (47.2)	52 (49.5)	
Ethnicity [1]					0.089****
White		8 (3.8)	4 (3.8)	4 (3.8)	
Black		109 (51.7)	56 (52.8)	53 (50.5)	
Mixed		88 (41.7)	46 (43.4)	42 (40.0)	
Education	167		**N= 85**	**N= 82**	0.496***
≤ Primary school		77 (46.1)	37 (43.5)	40 (48.8)	
≥ Secondary school		90 (53.9)	48 (56.5)	42 (51.2)	
Occupation	100		**N= 54**	**N= 46**	0.621***
Informal work		57 (57.0)	32 (59.3)	25 (54.3)	
Formal work		43 (43.0)	22 (40.7)	21 (45.7)	
Government assistance [2]	208		**N= 103**	**N= 105**	<0.001****
No		157 (75.5)	56 (54.4)	101 (96.2)	
Yes		51 (24.5)	47 (45.6)	4 (3.8)	

**NS: Nova Sussuarana*

***JSI/ME: Jardim Santo Inácio/Mata Escura*

[1] *6 (5.7%) participants self-declared of Asian ethnicity (JSI/ME community)*

[2] *Bolsa Família or Benefício de Prestação Continuada*

**** Chi-square test*

***** Fisher's exact test*

5.4.2 Households' and peri-domiciliary characteristics

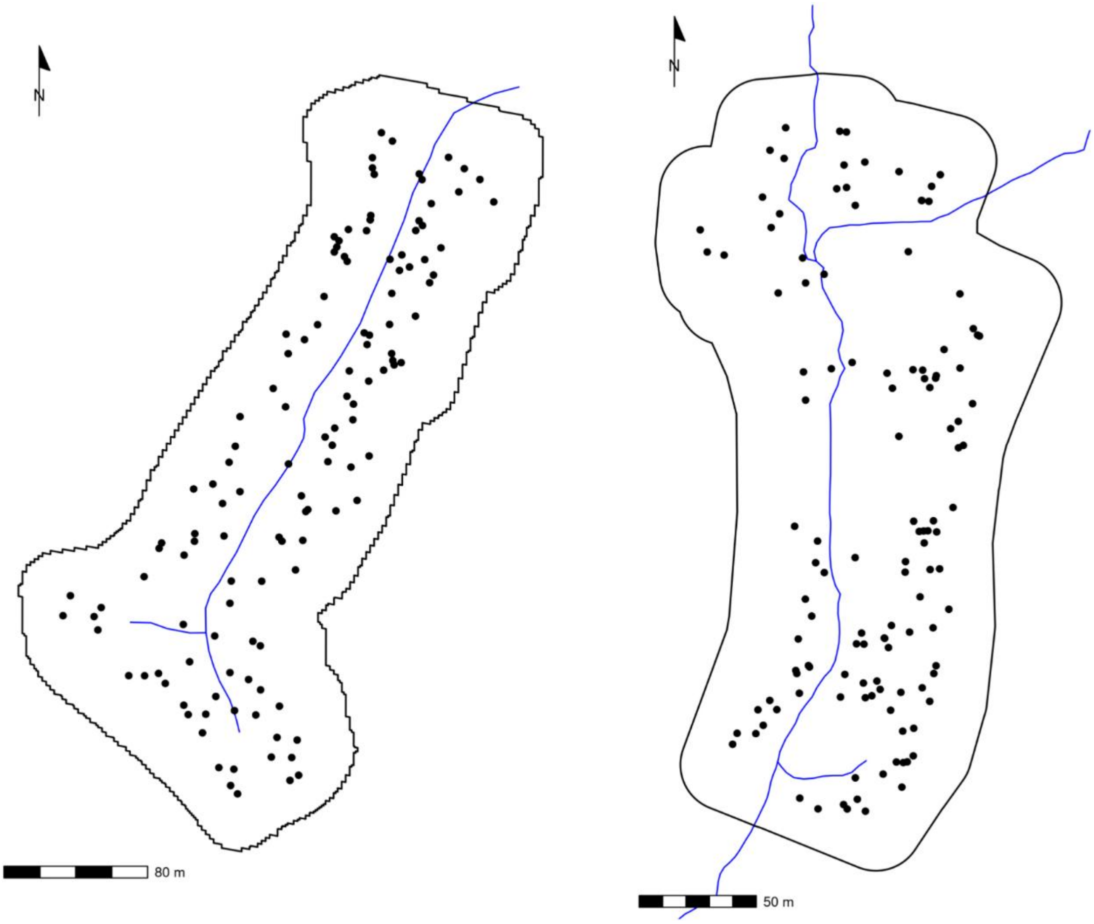


Figure 5.3 Household locations, jittered randomly by 5 meters to maintain anonymity.

Household locations are shown in Figure 5.3. Regarding peri-domiciliary characteristics, in NS, more households had cement as the primary flooring material (17.8% vs. 6.7%; p-value=0.008) and were close to slopes (26.2% vs. 10.4%; p-value=0.003) compared to the household of participants from JSI/ME. In JSI/ME, more households did not have a hydrometer (64.6% vs. 48.6%; p-value=0.024) compared to households in NS. Furthermore, a higher percentage of participants living in JSI/ME also reported more problems with the lack of water in their homes, the equivalent of 3 to 6 times a week (25.3% vs. 3.7%; p-value=<0.001) compared to households in NS. In NS, a higher percentage of households did not have paved access to the house (15.9% vs. 3.8%; p-value=0.005) compared to households in JSI/ME (Supplementary Material I: Descriptive Tables).

5.4.3 Perceived basic sanitation needs and intervention

There was no statistically significant difference in the perception of the need for basic sanitation intervention between participants who lived in NS and JSI/ME. Furthermore, sewage (87.1% NS vs. 84.9% JSI/ME) was the most reported intervention for participants in the two study communities, followed by urban cleaning and solid waste management (NS: 25.9%; JSI/ME: 32.6%). Despite that, a higher percentage of JSI/ME participants also reported the need for urban drainage and stormwater management intervention (17.4% vs. 7.1%; p-value=0.037) compared to the participants in NS (Table 5.2).

Table 5.2 Perceived and type sanitation needs reported by the study population

Variables	Responses	Overall (N= 213)	Communities		p-value
			NS* (N= 107)	JSI/ME** (N= 106)	
			Frequency (%)		
Intervention basic sanitation needs	213				0.756***
Yes		171 (80.3)	85 (79.4)	86 (81.1)	
No		42 (19.7)	22 (20.6)	20 (18.9)	
Intervention type [1]	229		**N=85**	**N= 86**	
Water supply [2]		1 (0.4)	-	1 (1.2)	
Sewage [3]		147 (62.2)	74 (87.1)	73 (84.9)	
Urban cleaning and solid waste management [4]		50 (21.8)	22 (25.9)	28 (32.6)	
Urban drainage and rainwater management [5]		21 (9.2)	6 (7.1)	15 (17.4)	
Others [6]		10 (4.4)	6 (7.1)	4 (4.7)	

**NS: Nova Sussuarana community*

***JSI/ME: Jardim Santo Inácio/Mata Escura community*

**** Chi-square test*

[1] Multiple choice

[2] Water supply: infrastructure activities and installations necessary for the public supply of drinking water, from collection to building connections and respective measuring instruments.

[3] Sanitary sewage: maintenance activities of infrastructure and operational facilities necessary for the adequate collection, transportation, treatment, and final disposal of sanitary sewage, from building connections to its final destination for the production of reused water or its adequate release into the environment.

[4] Urban cleaning and solid waste management: activities and provision and maintenance of operational infrastructures and facilities for collection, manual and mechanized sweeping, urban cleaning and conservation, transportation, transshipment, treatment, and environmentally appropriate final disposal of household solid waste and urban cleaning waste.

[5] Drainage and management of urban rainwater: activities, infrastructure, and operational facilities for rainwater drainage, transportation, detention, or retention to dampen flood flows, treatment, and final disposal of drained rainwater, including cleaning and preventive inspection of networks.

[6] Others: Paving and community organization (N=1); Shed Workshop for classes and reconstruction of community areas (N=1); Slope containment (N=5); Paving (N=3).

After selecting key perceived problems of basic sanitation, participants were asked to suggest potential interventions for the indicated needs. All responses were grouped into four categories (Table 5.3, and Supplementary Material I: Descriptive Tables), followed by the types of interventions indicated for each. When it came to sewage, the NS participants pointed out a variety of interventions. Integrated action (44.6%) and implantation/installation/construction (39.2%) were the most reported, with different measures suggested for each category. For instance, integrated sewage actions were proposed for sewer cleaning and sealing (26.5%), sewer cleaning and piping (23.5%).

For implementation/installation/construction interventions, the implementation of the sanitary sewage network and sewage piping (41.4%), in addition to sewer sealing (27.6%), was the most indicated by study participants (Table 5.3). In JSI/ME, most interventions indicated by participants were related mainly to implementation/installation/construction (50.7%) and maintenance (21.9%) of sewage systems dimensions. For implementation/installation/construction interventions were reported o sewage sealing (48.7%) and sewage pipe (25.6%). Thus, most indications for sewage maintenance interventions were cleaning (93.3%) (Table 5.3). See Supplementary Material I: Descriptive Tables for a full table of the type of sewage interventions reported by the study population.

For urban cleaning and solid waste management interventions, most participants in study communities proposed measures in different categories, with interventions related mainly to trash removal (40.9%) in NS and others (42.9%) in JSI/ME. In the trash removal category, the most reported interventions in NS were mainly to clean the square (22.2%) and river (22.2%), while in JSI/ME, in the category others, cleaning the community streets (69.2%) and community urban cleaning action (69.2%) were the most mentioned by participants (Table 5.3). See Supplementary Material I: Descriptive Tables for a full table of the type of urban cleaning and solid waste management interventions reported by the study population.

Table 5.3 Type of sewage and urban cleaning and solid waste management interventions reported by the study population

Type of intervention	Responses	Communities	
		NS*	JSI/ME**
		(N=74)	(N= 73)
		Frequency (%)	
Sewage			
Implementation/installation/construction[1]	66	**29 (39.2)**	**37 (50.7)**
Sewage sealing		8 (27.6)	19 (48.7)
Sanitary sewage network		12 (41.4)	7 (17.9)
Sewage piping		4 (13.8)	10 (25.6)
Maintenance[1]	23	**7 (9.5)**	**16 (21.9)**
Sewage cleaning		3 (42.9)	14 (93.3)
Integrated action[1]	43	**33 (44.6)**	**10 (13.7)**
Sewage sanitation, water supply, rainwater drainage, and solid waste management		-	2 (40.0)
Sewage cleaning and piping		8 (23.5)	4 (40.0)
Sewage cleaning and sealing		9 (26.5)	2 (20.0)
Urban cleaning intervention and solid waste management intervention			
Removal [1]	18	**9 (40.9)**	**9 (32.1)**
Square cleaning		2(22.2)	-
River cleaning		2(22.2)	1 (11.1)
Sewage cleaning		1 (11.1)	3 (33.3)
Others [1]	18	**5 (22.7)**	**13 (42.9)**
Community awareness		-	2 (15.4)
Community urban cleaning action		-	9 (69.2)

**NS: Nova Sussuarana community*

***JSI/ME: Jardim Santo Inácio/Mata Escura community*

[1] Multiple responses

5.4.4 Relationships of perceived basic sanitation intervention needs and the risk of infection from leptospirosis

The probability of leptospirosis seropositivity in a 35-year-old male was unequal throughout both study areas (Fig 2). There were clear hot-spots located across the study areas, with a probability of up to 49.9% in NS and 44.3% in JSI/ME.

The distribution of perceived intervention needs also varied across the study areas (Fig 4). The perceptions for all three intervention types clustered around the local river in both communities. The densities varied greatly: the highest density was for sewage interventions, with a maximum of 67 perceptions per point in NS and 54 in JSI/ME; the second highest was for urban cleaning, with a maximum density of 7 in NS and 12 in JSI/ME; and the lowest was drainage, with 4 perceptions per point in NS and 5 in JSI/ME as maximum densities (Figure 5.4).

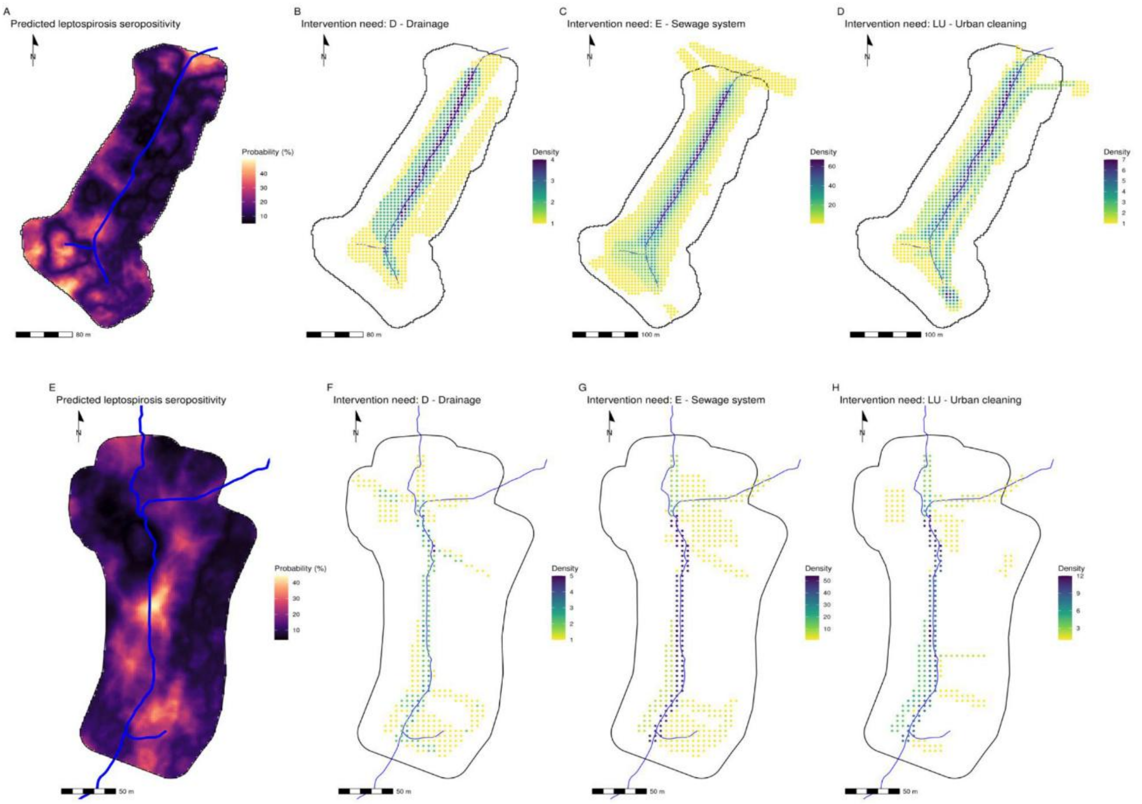


Figure 5.4 Maps of NS (top row) and JSI/ME (bottom row) showing predicted leptospirosis seropositivity across the study area (A and E) and perceived intervention needs for drainage (B and F), sewage system (C and G) and urban cleaning (D and H). Areas with no dots (white background) mean there were no perceptions from residents. The blue line represents the local river in each study area.

When comparing perceived intervention needs with predicted probability of leptospirosis seropositivity, there was evidence of a negative correlation across most perceptions (Table 5.4). In NS, for every 1% increase in predicted probability of leptospirosis seropositivity in a 35-year old male, there was a 1 – 2 % reduction in expected density for all perceptions (Sewage: RR = 0.98, 95% CI 0.98 – 0.98, p < 0.001; Urban cleaning: RR = 0.98, 95% CI 0.98 – 0.99, p <0.001; Drainage: RR = 0.99, 95% CI 0.99 – 0.99, p = 0.031). In JSI/ME, every 1% increase in predicted probability of leptospirosis seropositivity in a 35-year-old male resulted in a 1% reduction in expected density for perceived need of sewage-related intervention (RR = 0.99, 95% CI 0.99-1.00, p <0.001). In contrast, a 1% increase in predicted probability for leptospirosis seropositivity resulted in a 1% increase in expected density for perceived need of urban cleaning (RR = 1.01, 95% CI 1.01 – 1.02, p < 0.001). There was no evidence of a correlation between predicted probability for leptospirosis seropositivity and perceived need for drainage intervention (RR = 1.00, 95% CI 0.99 – 1.01, p = 0.537) (Table 5.4).

Table 5.4 Estimated effects of predicted probability of leptospiral seropositivity for a 35-year-old male on densities of each type of intervention need, by study area (NS, JSI/ME). Estimates are shown in Rate Ratios

Perceived sanitation needs intervention	Communities					
	NS*			JSI/ME**		
	Estimate	95% CI	p-value	Estimate	95% CI	p-value
Sewage	0.98	0.98, 0.98	<0.001	0.99	0.99, 1.00	<0.001
Urban cleaning	0.98	0.98, 0.99	<0.001	1.01	1.01, 1.02	<0.001
Drainage	0.99	0.99, 0.99	0.031	1.00	0.99, 1.01	0.537

**NS: Nova Sussuarana community*
***JSI/ME: Jardim Santo Inácio/Mata Escura community*

5.4.4.1 Subgroup analysis

In both study areas, there were higher densities of recorded perceptions for women compared to men (Supplementary Material I: Descriptive Tables). The relationship between the perceived intervention needs and the predicted probability of leptospirosis seropositivity did not vary when divided into genders.

When looking at the leptospirosis serological status, some differences appeared (Supplementary Material II: Figures). Firstly, seropositive individuals in NS only identified sewage system interventions as the perceived intervention needs in their community. The relationship between their perception densities and the predicted probability for leptospirosis seropositivity appeared to be non-existent. In JSI/ME, seropositive individuals identified all intervention types as needed in their communities. As in NS, the relationship between the densities of these and the predicted probability for seropositivity appeared to be non-existent. The relationship between the densities of the perceptions for seronegative individuals were the same as described in the full analyses.

5.5 Discussion

This study identified gaps between the perceived basic sanitation needs of residents of peripheral communities and the interventions carried out by the service provider. A relevant feature of this research was the investigation of the perception of these communities in a large urban centre in the context of the implementation of simplified sewage systems. In addition, we sought to understand if this perception contributed to exposure to diseases such as leptospirosis, which is associated with inadequate sanitation [60].

Our findings showed that despite sewage being a perceived basic sanitation need, residents also reported urban cleaning and solid waste management require attention, particularly in NS, requiring integrated actions and implementation/installation/construction regarding sewage. In JSI/ME, on the other hand, in addition to the needs related to implementation/installation/construction, maintenance was also an aspect frequently reported by residents. Here, we identified that community perceptions led to intervention recommendations beyond the service provider's plans, mainly focusing on the sanitary sewage network implementation/installation/construction. Although this was a relevant intervention, a previous study revealed that peripheral areas still lack full functional access to the sanitary sewage network [60]. Our findings integrate a health situation analysis that adopted a collaborative diagnostic approach to analyse the conditions in peripheral urban communities, revealing multiple vulnerability processes[94,105], persistent inequalities in sanitation services[60,106] and high exposure to risk factors for leptospirosis [55,58,61,84].

In Brazil, peripheral urban communities continue experiencing precarious provision of public services, such as sewage and trash collection[107], due to environmental racism[86] and the need for intersectoral actions. Collaborative approaches are needed to address these issues, focusing on identifying problems and disseminating interventions to enact local change based on the perception of those who experience this reality, including public institutions responsible. Even if community collaboration is through questionnaire responses, the potential to capture their perceptions is valid and reveals several processes of vulnerability, including limited participation in decision-making. In Brazil, the most precarious access to sanitation is more frequent among low-income and low-educational level people who self-declare as ethnically black living in the Northeast region[108], such as in the city of Salvador[106], where this study was conducted.

Our findings showed that most residents in NS reported sewer cleaning and sealing, as well as sewer cleaning and piping, as sanitation needs that require integrated intervention. Here, sealing refers to "*tamponamento do esgoto*" whereas piping means "*canalização do esgoto*". The most common implementation/installation/construction intervention was the sanitary sewage network. In JSI/ME, despite the similarity in the implementation/installation/construction dimension, most participants indicated interventions aimed at sewage sealing and piping. Sealing of polluted sewage/river was also a common intervention indication in the communities in our study. This intervention is often associated with inadequate urban intervention projects[109]. However, it is necessary to solve old problems in the study communities, such as the population's contact with polluted water, which contributes to diseases like leptospirosis[55] and arboviruses[110] and causes discomfort for residents.

Salvador has sealed several rivers, primarily in wealthier neighbourhoods or commercial districts, to eliminate odours and mosquitoes and improve landscapes[60,100]. More recently, two remnants of the city's rivers, the Camarajipe and the Lucaia, were sealed to make the Rapid Transit Bus (BRT) viable[109]. In contrast, peripheral communities face insufficient sewage interventions and sanitation components. While sealing courses of water is in most cases not an appropriated environmental intervention, the population's right to live without open sewage or contact with polluted river waters, especially during flooding, is a sufficient reason to implement this type of intervention in these contexts. The alternative and more desired option, the remediation and recuperation of courses of water, has been performed in few rivers of urban centres of Brazil, and has not been an available option in peripheral urban communities.

The indications of the types of sewage interventions perceived in the communities also show that, even in contexts where sociodemographic characteristics are homogeneous, as in our study, it is necessary to consider the environmental heterogeneities present in the communities. In our findings, we identified that, in NS there are more households in a situation of housing insecurity located near hillsides, and that do not have paved access to their homes. This scenario, combined with the inadequate disposal of sewage water on hillsides, contributes to landslides, increasing the community's vulnerabilities and risks[60]. In this study, we identified households in JSI/ME exposed to water insecurity, irregular supply, and a lack of hydrometers. The lack of historical guarantee of this right[101,106] in peripheral urban communities highlights the need for equitable and consistent sanitation and health intervention planning and considering these differences. Thus, planning sanitation and health interventions should be more equitable and consistent with local needs to be more effective in preventing diseases such as leptospirosis, improving the population's quality of life, and the environmental sustainability of territories[111].

Residents reported that the most common urban cleaning and solid waste management interventions involved removing solid waste in squares and streets. These findings were consistent with a qualitative and collaborative mapping study in four Salvador communities[55,98]. Residents reported addressing waste and sewage problems requires theoretical and practical approaches, such as educational activities and structural interventions. In NS, concerns were mainly related to a container near the community square that accumulates trash, while in JSI/ME, concerns were about trash accumulation at various community points. Trash inside the open sewer was a common concern, indicating insufficient solid waste management practices in poorer areas, such as peripheral urban communities.

We also identified that perceived needs for sanitation in communities correspond to the main risk factors for leptospirosis, as evidenced in previous studies in Salvador[55,58,61]. Contact with sewage water and mud is associated with the risk of human infection by *Leptospira*[58,112]. Furthermore, the most exposed groups are those without access to essential sanitation services and who face greater barriers to adopting preventive practices[77,113]. Progress still needs to be made in addressing risk factors for leptospirosis, such as sewage and trash, in peripheral urban communities. These communities continue having problems that require sanitation intervention in residents' perception. Furthermore, these problems persist despite the Sustainable

Development Goals (SDGs) to address access to drinking water and sanitation by 2030 [114] and the Basic Sanitation Law in Brazil [101]. Given this, we asked: what are the reasons that could explain the maintenance of this situation? What still needs to be done to effectively overcome these sanitation problems, which are risk factors for leptospirosis in these communities? Based on our findings, the current documents and agreements do not adequately guarantee the right to basic services for a dignified and healthy life.

Our analyses showed that residents' concerns mostly revolve around the central stream in both communities, with most perceptions clustering around this area. When comparing perceived intervention needs with the predicted probability of leptospirosis seropositivity, residents did not indicate that interventions needed to happen in the areas where our model predicted hotspots. Although this could be interpreted as a need for more local education on risks associated with leptospirosis, another interpretation would be that residents were more concerned with the impact of the polluted stream on their daily lives, such as bad smell, mosquito presence, tall vegetation, and frequent blockages and flooding.

The perceived importance of the stream as a matter of health concern, although contrasting with the risk model results, aligns with the ecological importance of the stream as a component of the landscape. Communities built on valleys and floodplains contribute to environmental contamination by pathogens and rat infestation, which are risk factors for leptospirosis[115]. Exposure to *Leptospira* can occur while transiting within the community, not necessarily in the peri-domiciliary environment. The poor environmental health and housing conditions faced in the communities foster rat infestation, allowing the expansion of environmental contamination by *Leptospira* beyond the reach of the stream water[55] .

The study has limitations due to its cross-sectional design, which limits inferring causality. Additionally, the study's focus on residents' perceptions of sanitation needs with a purely spatial perspective does not provide a comprehensive understanding of the perceptions reported by residents. A qualitative approach could deepen the understanding of these issues. While our study was designed to be representative of the communities, it is possible that community members who were most impacted by basic sanitation problems in the community have been more likely to respond. However, given the high participation rate of over 80% in each community, we expect the effect of this potential bias to be minimal. Another relevant aspect is the possible social and infrastructure differences between the communities, which may have limited the generalization of the results to other peripheral urban communities. This dimension can be influenced by the level of knowledge about basic sanitation and the time they have lived in the communities.

Other important limitations are those associated with our predictive model. Our model predicted the probability of leptospirosis seropositivity using individual serology data. A positive result in this data represents an immune response from being infected with leptospirosis, with or without symptoms. This infection could have been recent or historical. Therefore, it is an imperfect approximation to infection risk. A better measure of objective risk could have been environmental sampling for *Leptospira* bacteria, using either water or soil/mud. The model also shows that an individual lives, or can live, in every 2x2m pixel of the study area. Although we conducted a thorough analysis to identify the best variables to use for the predictive model, there could be other unmeasured variables that can better explain the variation. However, we still believe our model serves as a useful, albeit imperfect, proxy for infection risk.

To our knowledge, this is the first study to analyse sanitation needs based on residents' perceptions of peripheral urban communities in Salvador, Brazil, considering their spatial distribution and the relationship with the risk of leptospirosis. Our findings are valuable for understanding sanitation needs and their relationship with the risk of leptospirosis in peripheral urban communities and contribute to formulating intersectoral sanitation interventions and public policies aiming to reduce the risk of zoonotic diseases, such as leptospirosis.

This study employs a collaborative mapping methodology to understand local challenges and solutions, focusing on those experiencing them. It values community knowledge, encourages active data collection by community residents, and increases awareness of health risks. This approach can enhance demand for necessary changes to promote local health. However, it acknowledges that communities may face unique challenges, requiring adaptations in study planning. Future research on collaborative mapping may include broader community participation in formulating questionnaires, analysing data and interpreting results, using other forms of participation that encourage citizenship exercises, educational processes, and reflection on living in the environment of peripheral communities beyond perceptions. Thus, it could address other local needs contributing to the decreased risk of zoonotic diseases, such as leptospirosis, in peripheral urban communities. Combining this methodology with other epidemiological and environmental data would also strengthen the analyses. In addition, new studies could explore different topics related to basic sanitation and the determinants and conditions of health in these communities that impact the increase in cases of zoonotic diseases.

In this study, community insights provided by collaborative mapping could be integrated into ongoing urban planning and sanitation policies through dialogue with government service providers about the results of scientific research like this. Another alternative would be to include participatory methodologies, such as collaborative mapping, in urban planning and sanitation policies to prioritize and identify the locations and types of interventions that must be implemented to ensure they are more socioculturally appropriate and sustainable. Furthermore, in the case of sanitation policies, the sewage intervention model in communities like those in our study has as a guideline the promotion of community participation in the management and maintenance of interventions[93]. Although this is still incipient or absent in practice, it can be strengthened by the results of studies like this.

Finally, in Brazil, an important mechanism to institutionalize community mapping, as carried out in this study, in municipal health and sanitation strategies was the creation of the National Secretariat of Peripheries, linked to the Federal Government, recently published a Popular Mapping Guide[116] that aims to contribute to the strengthening of residents of the peripheries and subsidize the formulation of public policies aimed at these contexts.

5.5.1 Conclusion

Our findings showed that the prevention of diseases such as leptospirosis in peripheral urban communities requires integrated basic sanitation interventions, encompassing different components and aligned with the local needs perceived by residents. This study aimed to develop a deeper understanding of the health situation of peripheral urban communities in a large urban centre based on perceptions of sanitation-related needs and their relationship with diseases such as leptospirosis through a collaborative approach. In addition, we sought to contribute to an evidence base that would assist in the planning of priority sanitation interventions in similar settings characterized by limited resources to make them more effective in preventing zoonotic diseases.

5.6 Acknowledgements

We deeply thank the residents and communities of Nova Sussuarana and Jardim Santo Inácio/Mata Escura for participating in this study. We also thank the field research team members for their support and collaborative construction of this research. We thank all the authors and co-authors in the developed this research and the manuscript.

5.7 Supplementary Material I: Descriptive Tables

Table 5.5 Households' and peri-domiciliary characteristics of the study area

Variables	Responses	General (N=212)	Communities NS* (N=107)	Communities JSI/ME** (N= 105)	p value[1]
		Frequency (%)			
Household characteristics					
Floor material	212				0.008****
Ceramics or tile		181 (85.4)	84 (78.5)	97 (92.4)	
Cement		26 (12.3)	19 (17.8)	7 (6.7)	
Clay soil		3 (1.4)	3 (2.8)	-	
Other material [2]		2 (0.9)	1 (0.9)	1 (1.0)	
Wall material					0.550****
Brick with cladding		166 (78.3)	82 (76.6)	84 (80.0)	
Uncoated brick		44 (20.8)	23 (21.5)	21 (20.0)	
Reclaimed wood		2 (0.9)	2 (1.9)	-	
Ceiling material					0.350****
Concrete		112 (52.8)	56 (52.3)	56 (53.3)	
Asbestos tiles		75 (35.4)	41 (38.3)	34 (32.4)	
Roof tile		24 (11.3)	9 (8.4)	15 (14.3)	
Other material [3]		1 (0.5)	1 (0.9)	-	
Backyard material					0.149****
There is no backyard		103 (48.6)	44 (41.1)	59 (56.2)	
Clay soil		41 (19.3)	23 (21.5)	18 (17.1)	
Cement		57 (26.9)	34 (31.8)	23 (21.9)	
Ceramics		10 (4.7)	6 (5.6)	4 (3.8)	
Other material [4]		1 (0.5)	-	1 (1.0)	
Location of the home on a hillside					0.003***
Yes		39 (18.4)	28 (26.2)	11 (10.4)	
No		173 (81.6)	79 (73.8)	94 (89.5)	
Access to sanitation services					
Piped water	212				0.244****
Yes		210 (99.1)	107 (100)	103 (98.1)	
No		2 (0.9)	-	2 (1.9)	
Piped water from State Agency Public	210		**N= 107**	**N= 103**	0.116****
Yes		207 (9.6)	107 (100)	100 (97.1)	
No		3 (1.4)	-	3 (2.9)	
Water meter (Hydrometer)	206		**N= 107**	**N=99**	**0.024******
Yes		84 (40.8)	53 (49.5)	31 (31.3)	
No		116 (56.3)	52 (48.6)	64 (64.6)	

Don't know/didn't answer		6 (2.9)	2 (1.9)	4 (4.0)	
Lack of water at home					
There is no lack of water		94 (45.6)	68 (63.6)	26 (26.3)	**<0.001********
Less than 3 times a week		79 (38.3)	31 (29.0)	48 (48.5)	
3 to 6 times a week		29 (14.1)	4 (3.7)	25 (25.3)	
Don't know/didn't answer		4 (1.9)	4 (3.7)	-	
Peri-domiciliary characteristics					
Open sewer (<10 meters from the house)	211		**N= 107**	**N= 104**	0.110***
Yes		164 (77.7)	88 (82.2)	76 (73.1)	
No		47 (22.3)	19 (17.8)	28 (26.9)	
Sighting of rat (> 10 meters of house)	212		**N= 107**	**N= 105**	
Yes		140 (66.0)	76 (71.0)	64 (61.0)	0.121***
No		72 (34.0)	31 (29.0)	41 (39.0)	
Pavement (access to the house)					
Yes		191 (90.1)	90 (84.1)	101 (96.2)	**0.005********
No		21 (9.9)	17 (15.9)	4 (3.8)	

**NS: Nova Sussuarana*
***JSI/ME: Jardim Santo Inácio/Mata Escura*
[1]*Bold numbers mean P-value ≤ 0.05*
[2]*Red floor and parquet*
[3]*Slab and asbestos*
[4]*Backyard stuff*
**** Chi-square test*
***** Fisher's exact test*

Table 5.6 Full table of the type of sewage interventions reported by the study population

Sewage interventions	Responses	Communities	
		NS* (N=74)	JSI/ME** (N= 73)
		Frequency (%)	
Implementation/installation/construction[1]	66	**29 (39.2)**	**37 (50.7)**
Sewage sealing		8 (27.6)	19 (48.7)
River sealing		-	1 (2.6)
Sanitary sewage network		12 (41.4)	7 (17.9)
Sewage piping		4 (13.8)	10 (25.6)
River piping		2 (6.9)	-
Sewage piping and installation of sanitation sewage network		2 (6.9)	-
Installation and maintenance of sanitation sewage network		1 (3.4)	-
Maintenance[1]	23	**7 (9.5)**	**16 (21.9)**
Sewage cleaning		3 (42.9)	14 (93.3)
River cleaning		1 (14.3)	-
Sanitation sewage network		3 (42.9)	1 (6.7)
Sewage treatment		-	1 (6.7)
Integrated action[1]	43	**33 (44.6)**	**10 (13.7)**
Sanitation sewage, water supply, stormwater drainage, and solid waste management		-	1 (10.0)
Sewage cleaning and piping		8 (23.5)	4 (40.0)
River cleaning and piping		3 (8.8)	-
Sewage cleaning and sealing		9 (26.5)	2 (20.0)
Sewage cleaning, piping, and installation/maintenance of sanitation sewage network[2]		5 (14.7)	1 (10.0)
Sealing of sewage and installation/maintenance (unclogging) of sanitation sewage network		1 (2.9)	-
Sewage cleaning, sealing, and installation of sanitation sewage network		2 (6.1)	-
River cleaning and asphalt paving		1 (2.9)	-
Sewage piping and asphalt paving		1 (2.9)	2 (20.0)
Others[1]	14	**4 (5.4)**	**10 (13.7)**
Population relocation		-	2 (22.2)
Installation of sanitation sewage network and community awareness		1 (25.0)	-
Sewage sealing and population relocation		1 (25.0)	-
Sewage sealing and installation of recreational equipment		1 (25.0)	-
Community and institutional action		1 (25.0)	-
Institutional action		-	6 (66.7)
Community action		-	1 (10.0)
Don't know		-	1 (11.1)

**NS: Nova Sussuarana community*

***JSI/ME: Jardim Santo Inácio/Mata Escura community*

[1] Multiple responses

[2] Integrated implementation and maintenance actions were accounted for together.

Table 5.7 Full table of the type of urban cleaning and solid waste management interventions reported by the study population

Urban cleaning intervention and solid waste management intervention	**Responses**	**Communities**	
		NS* (N=22)	**JSI/ME** (N=28)**
		Frequency (%)	
Implementation/installation/construction[1]	6	**5 (22.7)**	**1(3.6)**
Stationary box (improved urban cleaning and collective action)		3 (60.0)	-
Stationary box (urban cleaning service)		1 (20.0)	-
Increased waste container (improved urban cleaning and collective action)		1 (20.0)	-
Install stationary box			1(100)
Removal[1]	18	**9 (40.9)**	**9 (32.1)**
Square cleaning		2(22.2)	-
Square cleaning and collective action		1(11.1)	-
Cleaning (unspecified)		-	3 (33.3)
Stationary box and street cleaning		1(11.1)	-
Stationary box cleaning		1 (11.1)	-
Trash and bush cleaning		1 (11.1)	-
River cleaning		2 (22.2)	1 (11.1)
Sewage cleaning		1 (11.1)	3 (33.3)
Backyard cleaning		-	2 (22.2)
Integrated action[1]	8	**3 (13.6)**	**5 (14.3)**
River cleaning and piping		2 (66.7)	-
River piping and sewage sealing		1 (33.3)	-
Sewage sanitation, water supply, rainwater drainage, and solid waste management		-	2 (40.0)
Sewage cleaning and sealing		-	2 (40.0)
River and greenery cleaning, and asphalt paving		-	1 (20.0)
Others[1]	18	**5 (22.7)**	**13 (42.9)**
Sewage piping		1 (16.7)	-
Sewage sealing		1 (16.7)	-
Sewage network		-	1(7.7)
Community awareness		-	2 (15.4)
Community urban cleaning action		-	9 (69.2)
Community and institutional urban cleaning action		3 (50.0)	1 (7.7)

**NS: Nova Sussuarana community*

***JSI/ME: Jardim Santo Inácio/Mata Escura community*

[1] Multiple responses

5.8 Supplementary Material II: Leptospirosis seropositivity model

5.8.1 Variable selection

We considered a number of known and possible risk factors for leptospirosis as variables to include in the predictive spatial model for leptospirosis seropositivity. These considered variables were:

- Rubbish piles
  - Domestic rubbish (known risk factor)
  - Construction materials (possible risk factor: rat presence)
  - Pruning (possible risk factor: rat presence)
  - All rubbish
- Drainage
  - Inadequate drainage points (known risk factor)
  - Adequate drainage points (known protective factor)
  - All drainage points (possible protective factor: reduced flooding)
- Roads
  - Soil roads (possible risk factor: potential for bacterial accumulation in mud)
  - Inadequate roads (possible risk factor: potential flooding)
  - Adequate roads (possible risk factor: potential flooding, also protective as reduced mud production)
- Sewage system
  - Open sewage points (known risk factor)
  - Sewage leakage (possible risk factor: exposure to sewage)
  - Open tubes (possible risk factor: exposure to sewage)
- Land cover
  - Soil (known risk factor)
  - Vegetation (known risk factor)
  - Impervious (known protective factor)
- Empty lots (possible risk factor: rat presence)
- Elevation (known risk factor)

Variable selection was carried out by assessing the strength of the associations between each variable and the outcome, leptospirosis seropositivity. These models included age, gender and study area as a priori variables (Table 5.8). All variables were also assessed for non-linear relationships with the outcome by using GAM models and observing the curves for each variable (Figure 5.8).

Table 5.8 Model Selection: Univariable estimates

Variable	Estimate	Confidence Interval (95%)		p-value
		Low	High	
Land Cover				
Soil (<25%)	0,92	0,87	0,98	0,005
Soil (>25%)	1,15	1,03	1,27	0,009
Vegetation	0,03	0,01	0,08	0,000
Impervious	0,03	0,01	0,10	0,000
Rubbish				
All	0,05	0,02	0,11	0,000
Domestic (<100m)	0,99	0,98	1,00	0,074
Domestic (>100m)	1,02	1,00	1,04	0,055
Construction materials	0,04	0,02	0,10	0,000
Pruning	0,02	0,01	0,06	0,000
Drainage				
Inadequate (<100m)	1,01	1,00	1,02	0,137
Inadequate (>100m)	0,95	0,88	1,00	0,082
Adequate	0,04	0,02	0,09	0,000
All	0,04	0,02	0,09	0,000
Roads				
All	0,03	0,01	0,08	0,000
Inadequate	0,04	0,02	0,11	0,000
Adequate	0,03	0,01	0,07	0,000
Soil roads (<50m)	0,99	0,97	1,01	0,327
Soil roads (>50m)	1,03	1,00	1,06	0,040
Empty lots	0,04	0,02	0,09	0,000
Sewage system				
All	0,03	0,01	0,07	0,000
Open sewage points	0,04	0,02	0,09	0,000
Sewage leakage	0,03	0,01	0,06	0,000
Elevation				
Elevation (<50m)	1,00	0,92	1,08	0,933
Elevation (>50m)	0,73	0,55	0,94	0,024

5.8.2 Model selection

Multi-variable models were built using the Akaike Information Criterion (AIC), selecting the lowest value. Variables were grouped using the groups above. Priority was given to models where a whole group was removed. The final model with the lowest AIC included soil, with a knot at 25%, and distance to pruning rubbish piles (Table 5.9). This model was then assessed for residual spatial correlation, using both mixed effects logistic regression models and geostatistical models. For the mixed effects model, we placed a random effect at the household location. The variance, although non-zero, was very small (variance = 2.275e-15), indicating that there was no residual spatial correlation. This was confirmed using a semivariogram (Figure 5.5). This confirmed there was no residual spatial correlation that needed to be accounted for.

Table 5.9 Model Selection: Multivariable estimates (AIC)

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Land Cover						
Soil (knot at 25%)	574,8	573	571,1	569,6	569,3	**399,7**
Vegetation	582,0	580,5	578,7	576,8	575,7	409,5
Impervious	581,3	580	578,3	576,4	575,6	409,3
None	580,0	578,5	576,7	574,8	573,7	407,5
Rubbish						
All	574,8	573	571,1	569,6	569,3	-
Domestic (knot at 100m)	-	-	-	-	-	-
Construction materials	573,2	571,3	570	568,2	569,2	-
Pruning	405,8	403,9	403,5	401,7	399,7	*
None	575,4	573,5	571,7	570	569,8	-
Drainage						
Inadequate (knot at 100m)	-	-	-	-	-	-
Adequate	576,2	574,4	572,5	570,8	-	-
All	574,8	573	571,1	569,6	-	-
None	574,8	573,2	571,3	569,3	-	-
Roads						
All	574,8	573	-	-	-	-
Inadequate	573,3	571,9	-	-	-	-
Adequate	573,1	571,2	-	-	-	-
Soil roads (knot at 50m)	-	-	-	-	-	-
None	572,8	571,1	-	-	-	-
Empty lots						
Included	574,8	573	571,1	-	-	-
Removed	573,1	571,4	569,6	-	-	-
Sewage system						
All	574,8	-	-	-	-	-
Open sewage points	575,0	-	-	-	-	-
Sewage leakage	572,7	-	-	-	-	-
None	573,0	-	-	-	-	-
Elevation (knot at 50m)						
Included	-	-	-	-	-	-
Removed	-	-	-	-	-	-

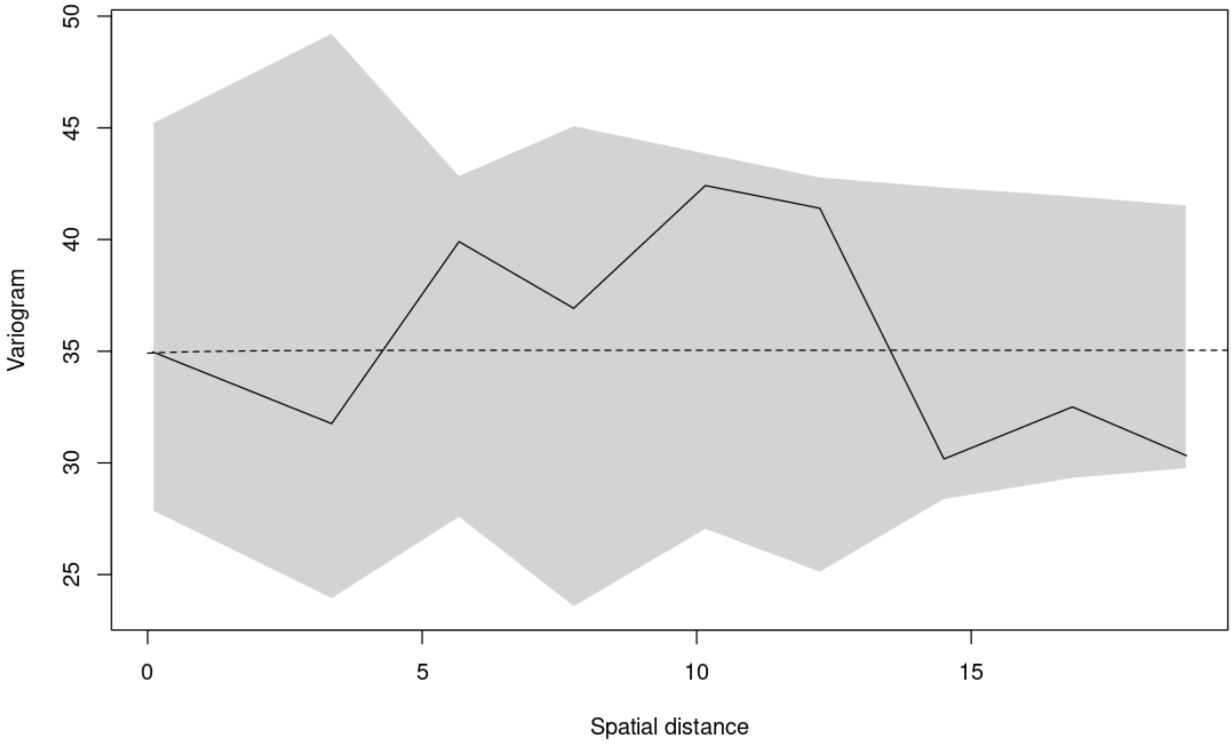


Figure 5.5 Semivariogram assessing residual spatial correlation of final model, which included percentage of soil land cover within a 20 meter buffer (with a knot at 25%) and distance to pruning rubbish piles.

5.8.2.1 Predictive performance

The model's predictive performance was assessed using a receiver operating characteristic curve (ROC curve) with cross-validation. The data set was divided into 5 equally sized folds. The predictive performance of the model was then assessed by leaving out one of these folds computing the predictions, comparing these predictions to the actual data. This was repeated 5 times, leaving out one fold each time. This estimated an area under the curve of 0.68, which indicated good predictive performance for this model.

5.9 Supplementary Material II: Figures

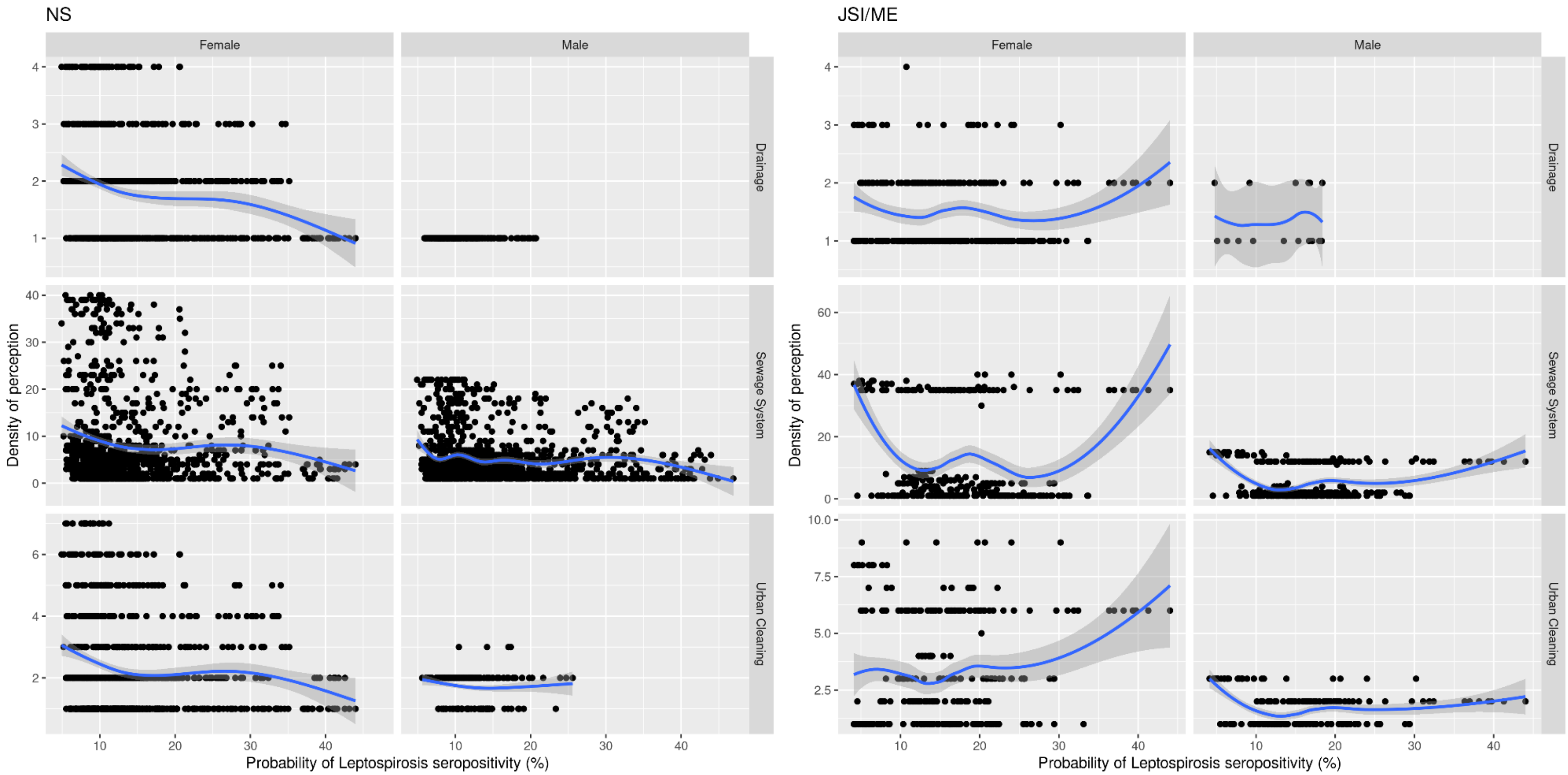


Figure 5.6 Graphs showing densities for each type of perceived intervention need against predicted probability of leptospirosis seropositivity for a 35-year old male, separated into gender of participants and study area

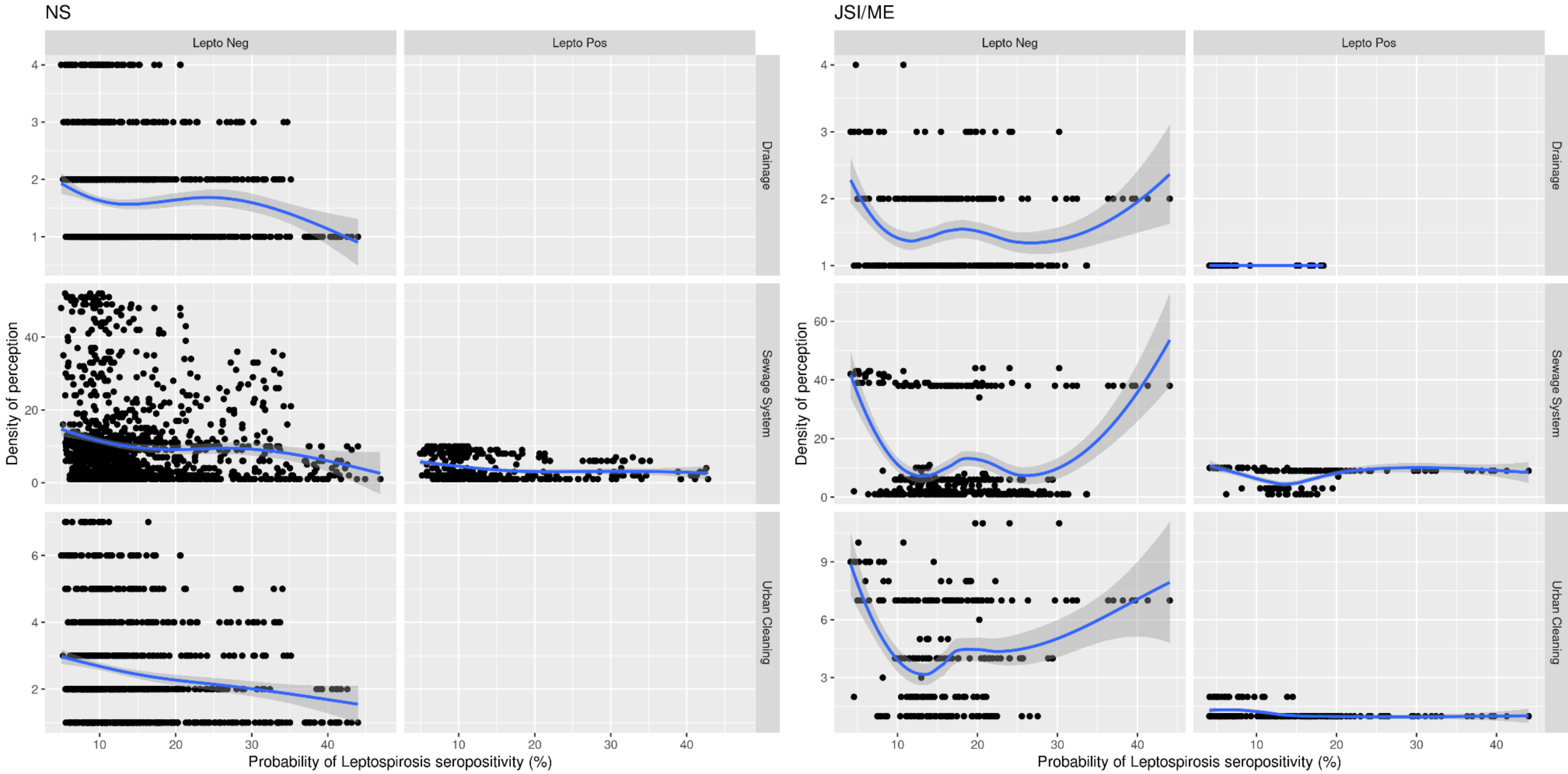
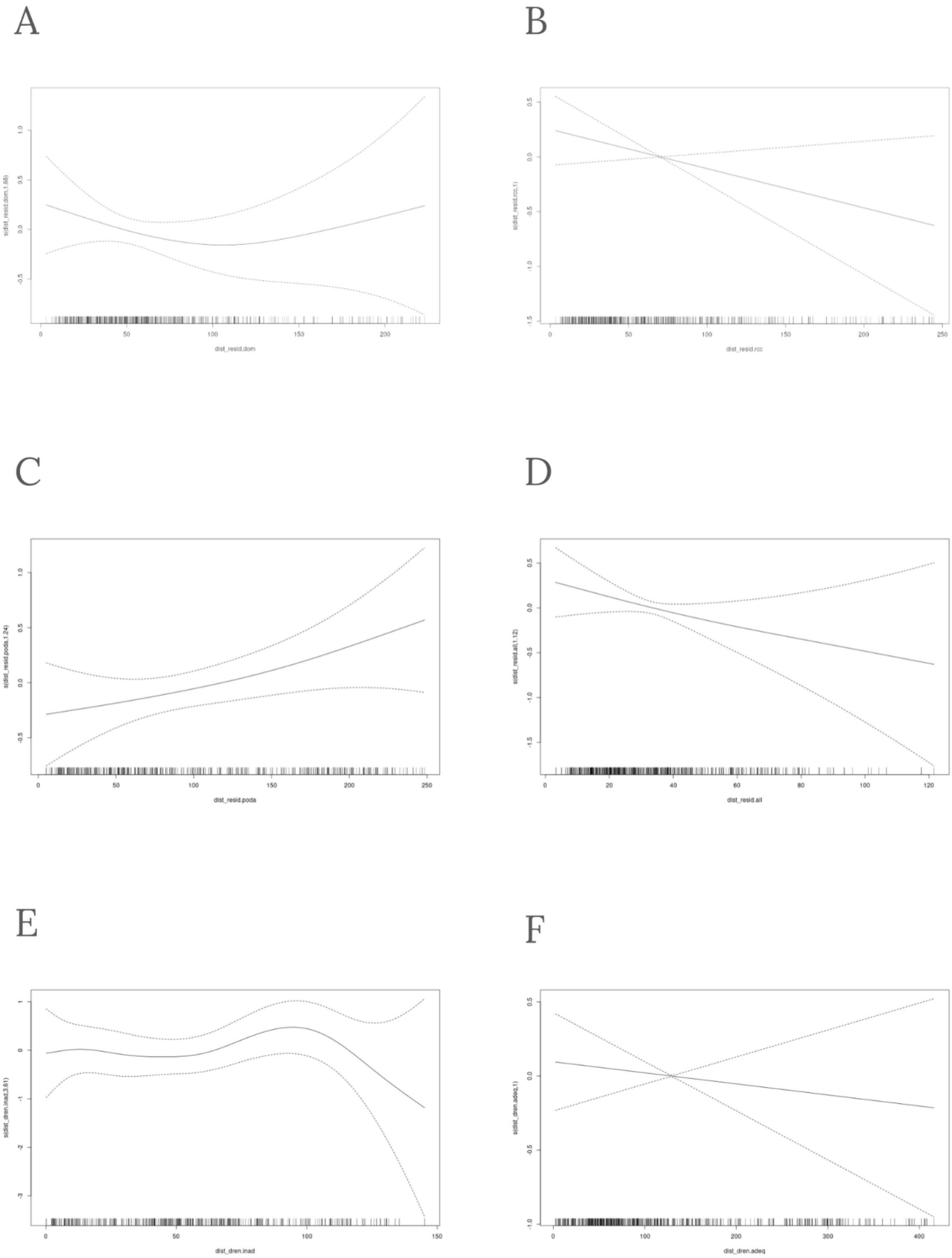


Figure 5.7 Graphs showing densities for each type of perceived intervention need against predicted probability of leptospirosis seropositivity for a 35-year old male, separated into leptospirosis serological status of participants and study area

5.10 Supplementary Material IV: GAM plots



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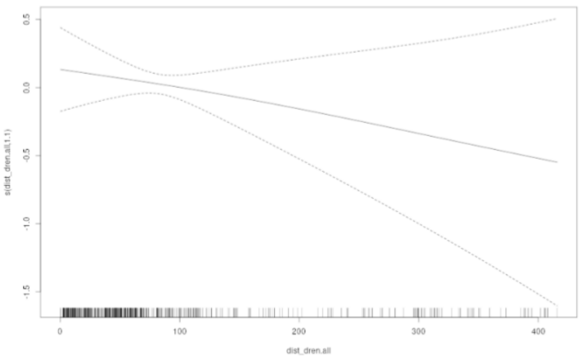

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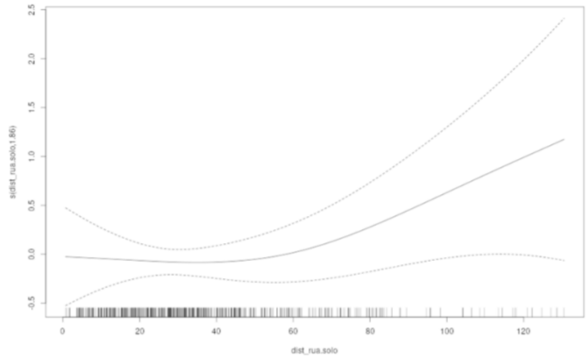

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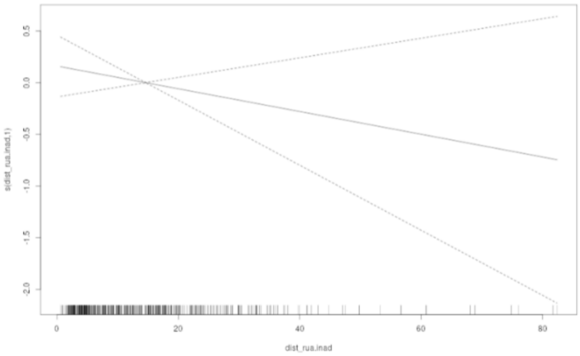

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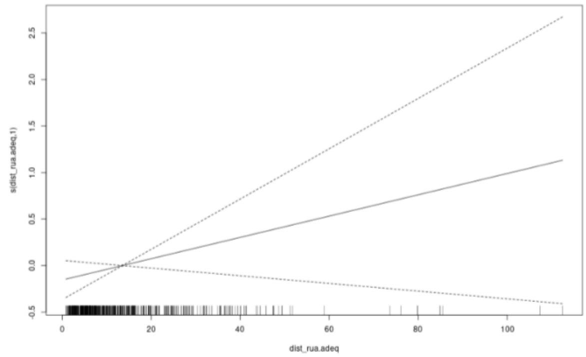

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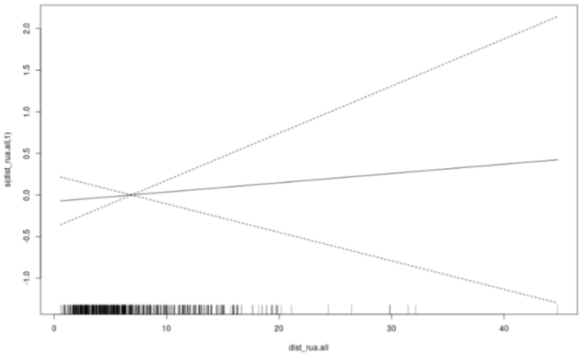

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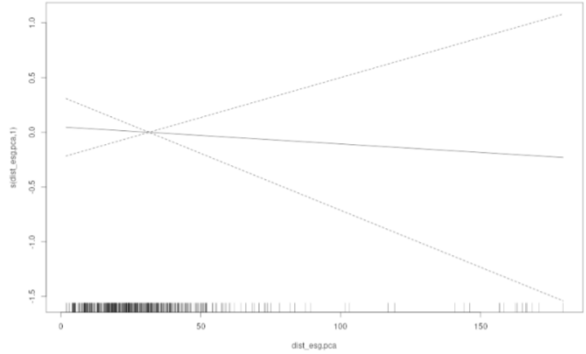

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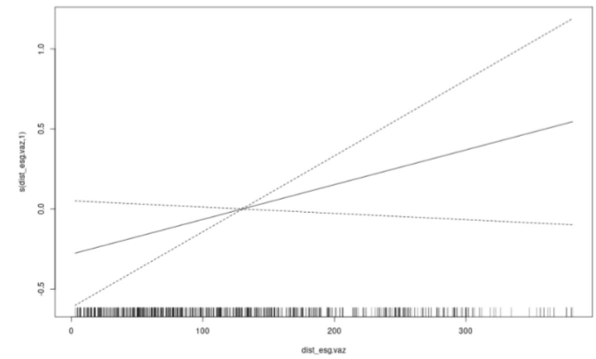

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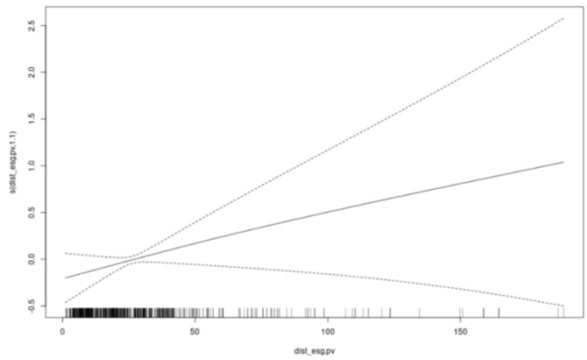

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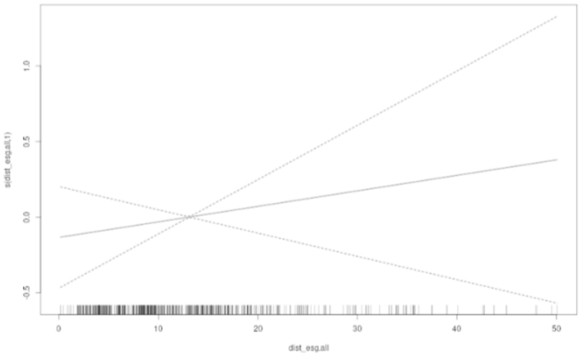

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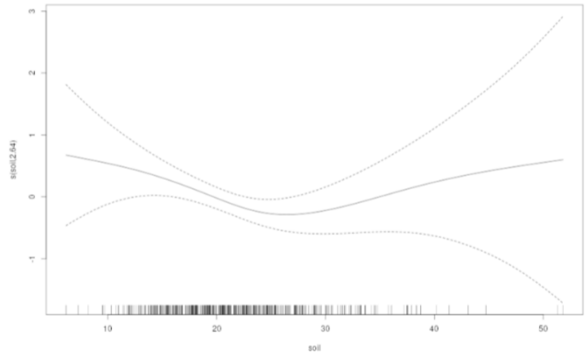

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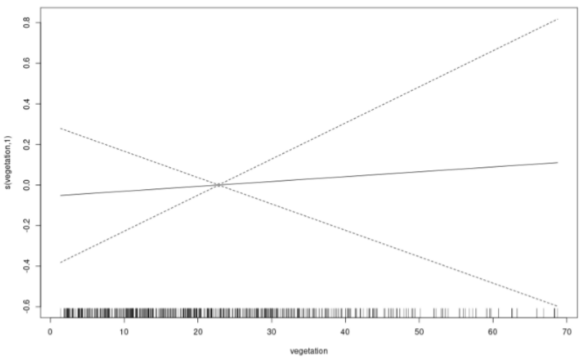

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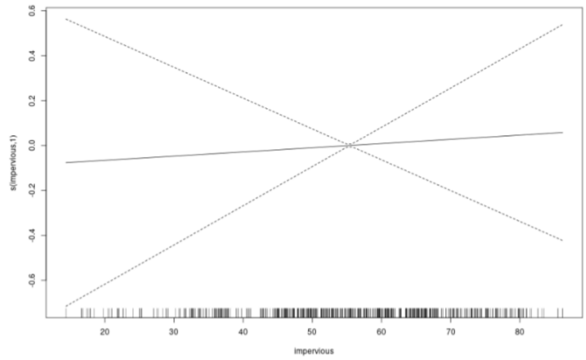

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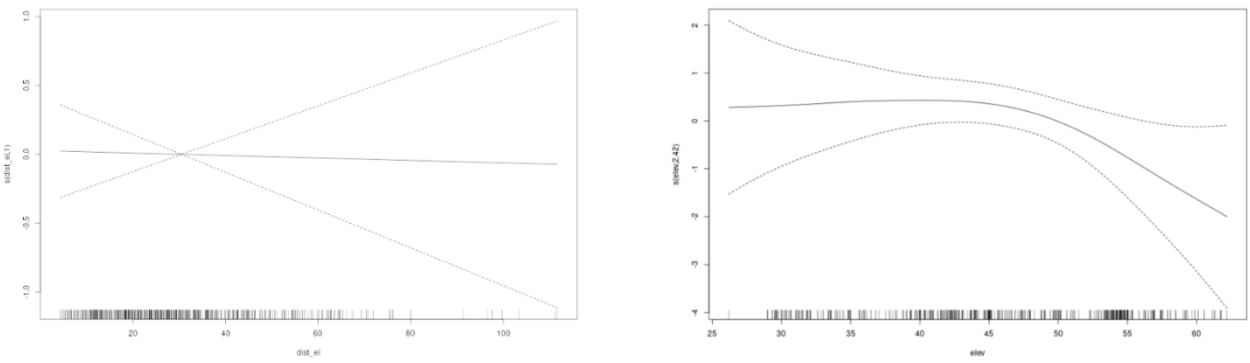

Figure 5.8 GAM plots used to assess for non-linear relationships. Variables assessed are: Distance to Rubbish Piles (A – Domestic, B – Construction, C – Pruning, D – All), Distance to Drainage (E – Inadequate, F – Adequate, G - All), Distance to Roads (H – Soil roads, I – Inadequate, J – Adequate, K – All), Distance to Sewage (L – Open sewage points, M – Sewage leaking, N – Open tubes, O- All), Land cover (P – Soil, Q – Vegetation, R – Impervious), Distance to Empty Lots (S) and Elevation (T).

Chapter 6 Discussion

In this section, I will expand on the contribution to knowledge for each of the papers presented in the thesis. I will also highlight and reinforce the limitations of each research project and propose areas for future research.

6.1 Chapter 2

In Chapter 2, we presented integrated step selection functions as a model to analyse fine scale human mobility. These models originate from animal movement ecology research, analysing how animals select specific aspects of their environment when moving through it. We applied this model in the context of human mobility, using telemetry data collected by GPS loggers. We presented an analysis of mobility in low-income neighbourhoods in Salvador, Brazil, to understand how movement may vary across socio-demographic factors and leptospirosis serological status.

To our knowledge, this is the first time step selection functions have been used to analyse human mobility data. The paper shows that they are a useful tool when trying to understand how specific environmental factors may affect movement choices. Although the aim of this paper was to explore this method of analysis rather than extract conclusions from the results, it did highlight some interesting differences in movements. Firstly, our results suggested that men and women had different mobility patterns through their neighbourhoods, particularly with respect to the community stream and open sewer points. Secondly, leptospirosis seropositive individuals may have been avoiding open sewer points, which contrasted with our expectation that they would be having more intense contact with these points. However, the low number of positive individuals in this sample did limit the interpretability of this result. Thirdly, our results vary from the findings that Owers et al., 2018, reported in their paper. We decided to delve deeper into this difference, which lead to the research presented in Chapter 3.

One of the limitations that this paper had was the low number of participants for epidemiological standards. Given the study of human mobility using such fine scale data is an emerging field, there were no clear suggestions on how to perform sample size calculations at the time of recruitment. Therefore, we opted to carry out convenience sampling targeting a specific number of individuals for each study area based on the resources available, balanced by gender and blind to the serological status of participants. This sampling may have resulted in an underpowered study with the consequences that this has on the interpretability of results. Another important limitation was the difficulty in interpreting the outputs from step selection functions, the selection coefficients. Although we have attempted to adapt the results for an epidemiological audience, we recognise that they are still abstract and complex. This can pose a challenge when communicating results, particularly to non-technical audiences. However, we believe they still provide important insight into movement behaviours and make an important contribution to understanding the effects of the environment on them.

We built upon the work carried out in this paper to perform the research presented in Chapter 3. Nevertheless, there is still research that could be carried out based on the analysis presented in this paper. There is a need to perform methodological research into the effects of violating some assumptions made in the use of step selection functions. This is particularly important in the assumption of autocorrelated movement, which is unlikely in human mobility through urban settings. This would involve carrying out simulation studies analysing the differences between those models that do violate the assumptions and those that do not. These simulation studies would allow researchers to violate one assumption at a time or combine different ones to assess how these may affect results. Additionally, step selection functions could be applied to other areas of research such as urban planning or the analysis of desire paths. A deeper exploration of creative applications of step selection functions would provide a better understanding of its usefulness.

6.2 Chapter 3

Chapter 3 builds upon the research carried out by both Owers et al., 2018, and us in chapter 2 and applies integrated step selection functions, along with other movement analysis methods, to understand movement characteristics of residents in low-income neighbourhoods of Salvador, Brazil. These are the same neighbourhoods as those studied in chapter 2. We collected telemetry data from residents over two periods, a baseline period and a follow up period after an intervention had been implemented. The aim of this paper was to understand movement characteristics of residents in high leptospirosis prevalence areas and contextualise these to the environmental risk factors associated with leptospirosis infection. Additionally, we were trying to analyse if the intervention had an effect on movement behaviours.

This paper presented suggestive evidence of interesting differences in movement behaviour. Firstly, we found evidence that men were staying at home more than women. We also found that residents would travel further, have higher activity spaces and spend slightly less time at home during heavy rainfall days. The interpretations for both of these results are presented and explained in the paper, but they are worth highlighting again here given their surprising nature. For both of these results we expected to see the opposite effect. This emphasises how objective data and quantitative analysis can cut through our preconceptions about how behaviours look or are performed, yielding a clearer understanding.

Our research showed that there may have also been some differences in movement behaviours that could be attributed to the intervention carried out. However, the methods used for this analysis had a number of limitations that limit the interpretability of these results. Some of these limitations are the same ones discussed for chapter 2, linked to the used of step selection functions for human mobility analysis. Although we believe that the methods we used helped to understand the effects of the intervention, there are other methods that could have more robustly assigned the causal link. For example, using difference-in-differences analysis. By comparing individuals who experienced the intervention to individuals who did not, we can attribute a strong causal link from the intervention to any observed effects. However, the data we had available, with significant loss to follow-up, did not allow us to effectively use this method. Future research attempting to analyse the effects of an intervention on movement could ensure that the data collection protocol allows for using this kind of analysis to produce more robust results.

We believe that this paper presents a compelling opportunity to investigate differences in movement behaviours in more depth. Qualitative research with the same participants, using in depth interviews or focus groups, would provide an excellent chance to understand how and why the gender differences and the pattern of movement during heavy rainfall days occur. Uncovering these mechanisms may highlight areas that could be targeted in future interventions. Additionally, combining these human mobility analyses with rat mobility analyses would help to understand if rat movements vary in similar ways and if their patterns of movements could be a significant driver in leptospirosis infections. In particular, understanding what seasonal variations rat mobility shows would also present a potential area for targeted action.

6.3 Chapter 4

In Chapter 4 we presented collaborative mapping as a tool to capture resident's perception of their neighbourhood's environment, focusing specifically on factors linked to leptospirosis. Although the research was not carried out in the same study areas as the other chapters of this thesis, the study areas used are very similar and share characteristics and challenges. The aim of the paper was to understand how residents' perception of risk varied from observed measures of the same or similar risk.

The research presented a method to understand this difference. Visiting the study areas and collecting the locations of known risk factors for leptospirosis, such as rubbish piles, allowed us to compare these to where resident's thought they were present. We also compared their perceptions to locations of leptospirosis positive households, used a proxy for environmental leptospirosis risk. This showed that, whilst residents correctly identified leptospirosis environmental risk factors and knew where they were located, they were better at identifying specific factors that had a direct impact on their day to day life, such as rubbish piles or open sewage points. Additionally, residents did not perceive leptospirosis as a major environmental issue, with one area not having any participants identifying it as a risk for their community. This showed that residents were probably more focused on tangible aspects of their environment and presented areas where community knowledge could be improved. Another important aspect of this paper was the collaboration with local residents to carry out the research tasks. This provided a number of benefits, including more community engagement and better quality answers from participants. This highlighted the positive contributions that local collaborations can have on research.

In spite of the positive contributions to knowledge that this paper generated, it presented a number of important limitations. One of the biggest challenges with regards to the analysis was the amount of missing data. Errors made during the data collection process compromised the quality of the demographic data, which in turn complicated the interpretation of the results. Although we made effort to remedy this, it did restrict the impact of the results. Additionally, all the participants who answered the questionnaire were considered heads-of-household, which could have introduced some biases. Another important limitation to highlight was leptospirosis households were used as a proxy for leptospirosis environmental risk. Although we explored creating a spatial prediction, as was performed later on in Chapter 5, the statistical models we were attempting to use were failing to converge. This was party due to the lack of spatial correlation at the scales we were using. We worked on this further in Chapter 5, but for the research in Chapter 4 we decided to use the physical locations instead. This simplified the analysis, but introduced a significant assumption that all environmental risk was strongly tied to the household location.

We used our experience from Chapter 4 to inform our analysis in Chapter 5. The work carried out in Chapter 4 could also be used to enhance research into risk perception, particularly environmental risks linked to other diseases. Another area of future research could be investigating violence in these contexts. Violence is an issue that is prevalent in all our study areas. It is often described using highly localised vocabulary, where residents identify specific corners or squares as being highly violent. Being able to collect these perceptions and understand the mechanisms behind how they arise would, firstly, allow violence to be included in spatial statistical modelling such as that used for leptospirosis and, secondly, identify if there are any environmental drivers for violence that could be altered.

6.4 Chapter 5

In Chapter 5 we visited two of the study areas from Chapter 2 and 3 to gather residents' perceptions on what interventions were needed in their communities. These were intervention areas, where structural changes were planned to be carried out. We also used collaborative mapping to identify the spatial distributions of these perceptions and compare them with the predictions from a leptospirosis seropositivity model. Our aim was to understand what interventions needed to happen and where they should be implemented, according to residents. We were also interested in analysing the relationship between the spatial distribution of these perceptions and the predicted spatial leptospirosis seropositivity, a proxy for infection risk.

Our research showed that residents from both study areas agreed that interventions were needed, and broadly agreed on the type of intervention. Some of these went beyond the plans that the service provider had put in place, highlighting the gap between the residents' needs and the local government's investment into the area. Additionally, we found that the perceptions of where interventions should occur did not match the areas where our statistical model predicted higher leptospirosis risk. This analysis identified that residents were very focused on the impact the local stream had on their lives and wanted actions to occur to mitigate the negative effects. Although these were not the areas where our models predicted the highest leptospirosis risk, they nevertheless had a significant impact on the residents lives. This result showed the importance of considering local needs and identified targets that could be utilised to build stronger relationships between these peripheral communities and local government.

An important limitation of this paper was the use of leptospirosis seropositivity as a proxy for leptospirosis risk. This was a similar limitation to that discussed in the section about Chapter 4. Using household locations as the main data for the statistical models assumes that all exposures and infections occur in or near these houses. This is a significant assumption that may not be true. However, this has been often used and repeating this type of analysis allowed us to fulfil the research objectives. Additionally, although we explored using more sophisticated models to analyse and predict, such as geostatistical models, we found that at the scale of our data there was not residual spatial correlation (Figure 5.5). Therefore, we decided to use the simplest model that best fit and explained our data, which in this case was a logistic regression model.

Although the methods used in this paper to identify perceptions had some qualitative characteristics, deeper qualitative research may be useful to better understand residents' perceptions. Carrying out focus group discussions or one-to-one interviews about their concerns would allow a better intervention design that would consider the residents' needs. Comparing perceptions with spatial rasters also opens up opportunities to analyse different relationships. For example, perceptions could be compared to rat presence rasters or leptospiral environmental contamination rasters. These analyses also have applications in other fields where perceptions have a role, such as urban planning.

6.5 Conclusion

The aims of this thesis were to investigate two aspects of leptospirosis disease transmission: the effects of human mobility and the effects of environmental perceptions. We set out to understand how mobility could be analysed and how these analyses could be used in the context of leptospirosis environmental epidemiology. We were also interested in investigating perceptions of local environments, focusing on perceptions of health risks and community needs. The four papers included in this thesis describe the work carried out to reach these aims. Each paper highlights the strengths of the different methods whilst also acknowledging the challenges and limitations involved.

Overall, our research has shown the importance that local fine-scale environments can have on peoples' health and well-being. Uncovering patterns and mechanisms by which residents move through and perceive their environments has provided a solid foundation upon which further research can build. They have also highlighted targets for interventions to improve and areas in which local government could work on. We have shown the benefits of exploring methods used in other fields of research. Incorporating these methods into human health and epidemiology contexts can be difficult at first, but learning how to adapt them can contribute to generating positive impacts on global health.

Although there are challenges with working with both fine-scale telemetry and spatial perception data, we have shown that the insights they provide are highly beneficial to advancing knowledge on infectious disease epidemiology and, more specifically, leptospirosis environmental epidemiology.

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Appendix A Lancaster Ethics Application

Research Ethics Application Form v1.8.1 RECR

Human movement and infectious disease - Approved

Information Regarding this Research Project

Are you conducting a research project?

(for more information on research projects please see our ethics pages)

(•) Yes ( ) No

Does your research only involve animals?

( ) Yes (•) No

Are you undertaking this research as/are you filling this form out as:

( ) Academic/Research Staff
( ) Non Academic Staff
( ) Staff Undertaking a Programme of Study
(•) PhD or DClinPsy student
( ) Undergraduate, Masters, Master by Research, MPhil or other taught postgraduate programme

Which Faculty are you in?

Faculty of Health and Medicine

Which department are you in?

Lancaster Medical School

Will your project require NHS REC approval? (If you are not sure please read the guidance in the information button)

- ○ Yes
- ● No

Do you need Health Research Authority (HRA) approval? (Please read the guidance in the information button)

- ○ Yes
- ● No

Have you already obtained, or will you be applying for ethical approval, from another institution outside of Lancaster University? (For example, an external institution such as: another University's Research Ethics Committee, the NHS or an institution abroad (eg an IRB in the USA)? Please select one of the following:

- ● No, I do not need ethical approval from an external institution.
- ○ Yes, I have already received ethical approval from an external institution.
- ○ Yes, I will be applying for ethical approval from an external institution after I have received confirmation of ethical approval from my Faculty Research Ethics Committee (FREC) at Lancaster University, if the FREC grants approval.

Is this an amendment to a project previously approved by Lancaster University?

- ○ Yes
- ● No

Will your research involve any of the following? (Multiple selections are possible, please see i icon for details)

- [ ] Human Participants
- [x] Data relating to humans (Secondary/Pre-existing data only)
- [ ] Data collection from online sources such as social media platforms, discussion forums, online chat-rooms
- [ ] Human Tissue
- [ ] None of the above

Project Information

Please confirm/amend the title of this project.

Human movement and infectious disease

Estimated Project Start Date: 02/01/2023

Estimated End Date: 30/09/2025

Is this a funded Project?

(•) Yes ( ) No

Funding Information

Funding information

What is the ACP Reference? N/A

What is the Agresso ID? N/A

Please note

Your ACP reference number can be found on your grant application, it will start with an A and be followed by 6 numbers, e.g. A123456 Your Agresso ID is your grant code for expenditure allocated by post-award, e.g. EAA7001.

What is the funding organisation? Medical Research Council (MRC)

What is your external grant reference? (if you do not have one, please enter "N/A")

N/A

Research Site(s) Information

Will you be recruiting participants from research sites outside of Lancaster University? *(E.g. Schools, workplaces, etc; please read the guidance in the information button for more information)*

( ) Yes (•) No

Applicant Details

Are you the named Principal Investigator at Lancaster University?

○ Yes ◉ No

Please check your contact details are correct. You can update these fields via the personal details section located in the top right of the screen. Click on your name and email address in the top right to access "Personal details". For more details on how to do this, please read the guidance in the information button.

First Name

Pablo

Surname

Ruiz Cuenca

Department

Lancaster Medical School

Faculty

Faculty of Health and Medicine

Email

p.ruizcuenca@lancaster.ac.uk

Principal Investigator

Search for principal investigator name: *If you cannot find the PI in the system please contact rso-systems@lancaster.ac.uk to have them added.*

First Name

Emanuele

Surname

Giorgi

Department

Lancaster Medical School

Faculty

Faculty of Health and Medicine

Email

e.giorgi@lancaster.ac.uk

Supervisor Details

Search for your supervisor's name. *If you cannot find your supervisor in the system please contact rso-systems@lancaster.ac.uk to have them added.*

First Name

Emanuele

Surname

Giorgi

Department

Lancaster Medical School

Faculty

Faculty of Health and Medicine

Email

e.giorgi@lancaster.ac.uk

Do you need to add a second supervisor to sign off on this project?

(•) Yes ( ) No

Search for your secondary supervisor's name. *If you cannot find your supervisor in the system please contact rso-systems@lancaster.ac.uk to have them added.*

First Name

Jonathan

Surname

Read

Department

Lancaster Medical School

Faculty

FHM

Email

jonathan.read@lancaster.ac.uk

Additional Team Members

Other then those already added, please select which type of team members will be working on this project:

- [ ] I am not working with any other team members.
- [ ] Staff
- [ ] Student
- [x] External

Please list all external contacts here:

First Name

Federico

Surname

Costa

Organisation

Instituto de Saude Coletiva, Universidad Federal da Bahia

Data Origin

Is the data you will be using in the public domain or from data repositories?

○ Yes ◉ No

Do you intend to use data about humans from online sources such as social media platforms, discussion forums, or online chat rooms?

○ Yes ◉ No

Has consent for the use/reuse of the data for research purposes been obtained?

◉ Yes ○ No ○ I don't know

Will you protect confidentiality and anonymity in your (re)analysis of the data?

◉ Yes ○ No ○ I don't know

Data Analysis

Do you intend to conduct a secondary analysis of existing research data?

◉ Yes ○ No

Was the data ethically obtained and was approval granted from a research ethics committee for its use?

◉ Yes ○ No ○ I don't know

Does the consent obtained from participants cover the proposed re-use of the research data for your current project?

◉ Yes ○ No ○ I don't know

Will you obtain the data in anonymised format?

- ( ) Yes
- (•) No
- ( ) I don't know

General Queries

Does the funder or any organisations involved in the research have a vested interest in specific research outcomes that would affect the independence of the research?

- ( ) Yes
- (•) No
- ( ) I don't know

Does any member of the research team, or their families and friends, have any links to the funder or organisations involved in the research?

- ( ) Yes
- (•) No
- ( ) I don't know

Can the research results be freely disseminated?

- (•) Yes
- ( ) No
- ( ) I don't know

Will you use data from potentially illicit, illegal, or unethical sources (e.g. pornography, related to terrorism, dark web, leaked information)?

- ( ) Yes
- (•) No
- ( ) I don't know

Will you be gathering/working with any special category personal data?

- (•) Yes
- ( ) No
- ( ) I don't know

Are there any other ethical considerations which haven't been covered?

- ( ) Yes
- (•) No
- ( ) I don't know

REC Review Details

Based on the answers you have given so far you will need to answer some additional questions to allow reviewers to assess your application.

It is recommended that you do not proceed until you have completed **all of the previous questions**.

Please confirm that you have finished answering the previous questions and are happy to proceed.

☑ I confirm that I have answered all of the previous questions, and am happy to proceed with the application.

You have stated that you are research only involves data.

☑ Please confirm that your research will have no direct involvement with human participants.

Questions for REC Review

Summarise your research protocol in lay terms (indicative maximum length 150 words).

Note: The summary of the protocol should concisely but clearly tell the Ethics Committee (in simple terms and in a way which would be understandable to a general audience) what you are broadly planning to do in your study. Your study will be reviewed by colleagues from different disciplines who will not be familiar with your specific field of research and it may also be reviewed by the lay members of the Research Ethics Committee; therefore avoid jargon and use simple terms. A helpful format may include a sentence or two about the background/ "problem" the research is addressing, why it is important, followed by a description of the basic design and target population. Think of it as a snapshot of your study.

This research will use data from individuals living in urban slums to assess how human movement is associated to and can affect infection status. The disease of focus will be leptospirosis, a bacterial infection that is transmitted by rat urine. However, other diseases with strong environmental drivers will also be explored, including dengue and Chikungunya, both diseases transmitted by mosquitoes. Human movement will be recorded using GPS trackers over a pre-agreed period of time. These trackers record coordinates every 35 seconds, with an accuracy of 5 meters. The project will also include individual's perception of risk. All this data will be collected by our external partner, the Universidad Federal da Bahia, in Salvador, Brazil. The combination of this data will be used to understand how human movement is linked to infection status, how movement can be used to improve infection models and how risk perception can affect movement and in turn affect infection. The analysis will be carried out by myself, affiliated with Lancaster University.

State the Aims and Objectives of the project in Lay persons' language.

Aim: Disentangle the effects of human movement on infectious diseases to improve improve infectious disease models

Objectives:
Identify patterns of movement in urban slums that are linked to specific socio-demographic characteristics
Identify patterns of movement associated with infection status
Explore how human movement can be included in infectious disease models
Understand how individual's risk perception can affect their movement behaviours

Information about the Research

Will you be sharing your data with any other organisation?

○ Yes ◉ No

What are your dissemination plans? E.g publishing in PhD thesis, publishing in academic journal, presenting in a conference (talk or poster).

PhD by publication, publishing 3 journal articles over the course of the next 3 years. This might also include presenting at conferences.

Data Origin

You have indicated that the data you will be using is not in the public domain. Please explain how the records will be obtained and indicate the original purpose for which the data was collected.

The data will be securely shared by our external partner, the Universidad Federal da Bahia, via RedCap and OneDrive. This data was collected to assess the effectiveness of an intervention against environmental transmission of infectious diseases. Part of this includes performing secondary data analysis to answer specific epidemiological questions.

Data Analysis

You answered ‘no’ to this question: Will you obtain the data in anonymised format? Please provide more information about this, for example, was anonymity offered to participants in the original study.

Anonymity was offered to participants and will be ensured in any publications. However, given that the intended analysis requires use of specific coordinates, individual's characteristics and household locations, anonymity at this stage cannot be incorporated. Publications originating from this project will not show individual's details, only summary statistics at an aggregated level, ensuring that their information cannot be traced back to them.

General Queries

You have indicated that you will be gathering/working with special category data. Please confirm here how you will comply with data protection law (GDPR) for use of special category personal data.

Data is special category as it will include individual's personal information (name, gender, age, household income, etc.) and health information (infection markers for leptospirosis, Chikingunya virus, dengue, COVID-19). I will also be receiving exact household locations and individual's movements, through location tracking. Data will be stored securely on the cloud, using a OneDrive server hosted by Lancaster University. Any data that is downloaded locally will be saved on a computer that is encrypted and password-protected. I will follow Lancaster University's guidance on handling the data at all times.

Data Storage

How long will you retain the research data?

I will retain the research data for 10 years

How long and where will you store any personal and/or sensitive data?

Personal and/or sensitive data will be stored in a encrypted, password-protected laptop if downloaded locally. Otherwise, it is stored on the cloud using a safe server, OneDrive, hosted by Lancaster University

Please explain when and how you will anonymise data and delete any identifiable record?

I will receive non-anonymised data which includes names, addresses, ethnicity, georeferrenced household locations, georeferrenced locations visited and health information. Any surplus information that is not necessary, such as names, will be deleted. Data will be anonymised before publication, and will only be made available in aggregated formats to preserve anonymity.

Project Documentation*

Important Notice about uploaded documents:

When your application has been reviewed if you are asked to make any changes to your uploaded documents please highlight the changes on the updated document(s) using the highlighter so that they are easy to see.

In addition to completing this form you must submit all supporting materials.

Please indicate which of the following documents are appropriate for your project:

- ☐ Research Proposal (DClinPsy)
- ☐ Advertising materials (posters, emails)
- ☐ Letters/emails of invitation to participate
- ☑ Consent forms
- ☐ Participant information sheet(s)
- ☐ Interview question guides
- ☐ Focus group scripts
- ☐ Questionnaires, surveys, demographic sheets
- ☐ Workshop guide(s)
- ☐ Debrief sheet(s)
- ☐ Transcription (confidentiality) agreement
- ☑ Other
- ☐ None of the above.

Please upload the documents in the correct sections below:

Please ensure these are the latest version of the documents to prevent the application being returned for corrections you have already made.

Please upload all consent forms to be used in this project.

Documents

Type	Document Name	File Name	Version Date	Version	Size
Consent Form	TCLE_responsavel_legal_emenda_2022	TCLE_responsavel_legal_emenda_2022.pdf	14/11/2022	1	306.8 KB
Consent Form	TCLE_grupo_focal_emenda2022	TCLE_grupo_focal_emenda2022.pdf	14/11/2022	1	230.0 KB
Consent Form	TCLE_adult_emenda2022	TCLE_adult_emenda2022.pdf	14/11/2022	1	235.7 KB
Consent Form	TALE_12_17_anos_emenda2022	TALE_12_17_anos_emenda2022.pdf	14/11/2022	1	220.4 KB

Please upload any other relevant documentation related to this project.

Documents

Type	Document Name	File Name	Version Date	Version	Size
Other	Brazil-ethics-approval	Brazil-ethics-approval.pdf	14/11/2022	1	54.5 KB

Declaration

Please Note

Research Services monitors projects entered into the online system, and may select projects for quality control.

All research at Lancaster university must comply with the LU data storage and governance guidance as well as the General Data Protection Regulation (GDPR) and the UK Data Protection Act 2018. (Data Protection Guidance webpage)

- [x] I confirm that I have read and will comply with the LU Data Storage and Governance guidance and that my data use and storage plans comply with the General data Protection Regulation (GDPR) and the UK Data Protection Act 2018.

Have you that you have undertaken a health and safety risk assessment for your project through your departmental process? (Health and Safety Guidance)

- [x] I have undertaken a health and safety assesment for your project through my departmental process, and where required will follow the appropriate guidance for the control and management of any foreseeable risks.

When you are satisfied that this application has been completed please click "Request" below to send this application to your supervisor for approval.

Signed: This form was signed by Mr Emanuele Giorgi (e.giorgi@lancaster.ac.uk) on 28/11/2022 13:15

Please press "Request" to send this application to your second supervisor.

Signed: This form was signed by Dr Jonathan Read (jonathan.read@lancaster.ac.uk) on 28/11/2022 10:03

As you have stated that you are not the PI you will need to have the PI sign off on this application.

As the applicant please click "Request". *Please note that you cannot request a signature from yourself.*

Signed: This form was signed by Mr Emanuele Giorgi (e.giorgi@lancaster.ac.uk) on 28/11/2022 13:15

Please read the terms and conditions below:

- You have read and will abide by Lancaster University’s Code of Practice and will ensure that all staff and students involved in the project will also abide by it.
- If appropriate a confidentiality agreement will be used.
- You will complete a data management plan with the Library if appropriate. Guidance from Library.
- You will provide your contact details, as well as those of either your supervisor (for students) or an appropriate person for complaints (such as HoD) to any participants with whom you interact, so they know whom to contact in case of questions or complaints?
- That University policy will be followed for secure storage of identifiable data on all portable devices and if necessary you will seek guidance from ISS.
- That you have completed the ISS Information Security training and passed the assessment.
- That you will abide by Lancaster University’s lone working policy for field work if appropriate.
- On behalf of the institution you accept responsibility for the project in relation to promoting good research practice and the prevention of misconduct (including plagiarism and fabrication or misrepresentation of results).
- To the best of your knowledge the information you have provided is correct at the time of submission.
- If anything changes in your research project you will submit an amendment.

Applicant Only: To complete and submit this application please click "Sign" below:

Signed: This form was signed by Pablo Ruiz Cuenca (p.ruizcuenca@lancaster.ac.uk) on 28/11/2022 14:27

Appendix B Lancaster Ethics Approval

Name: Pablo Ruiz Cuenca

Supervisor: Emanuele Giorgi

Department: Lancaster Medical School

FHM **REC Reference:** FHM-2022-3236-RECR-1

Title: Human movement and infectious disease

Dear Pablo Ruiz Cuenca,

Thank you for submitting your ethics application in REAMS, Lancaster University's online ethics review system for research. The application was recommended for approval by the FHM Research Ethics Committee, and on behalf of the Committee, I can confirm that approval has been granted for this application.

As Principal Investigator/Co-Investigator your responsibilities include:

- ensuring that (where applicable) all the necessary legal and regulatory requirements in order to conduct the research are met, and the necessary licences and approvals have been obtained.

- reporting any ethics-related issues that occur during the course of the research or arising from the research to the Research Ethics Officer at the email address below (e.g. unforeseen ethical issues, complaints about the conduct of the research, adverse reactions such as extreme distress).

- submitting any changes to your application, including in your participant facing materials (see attached amendment guidance).

Please keep a copy of this email for your records. Please contact me if you have any queries or require further information.

Yours sincerely,

Dr Laura Machin
Chair of the Faculty of Health and Medicine Research Ethics Committee
fhmresearchsupport@lancaster.ac.uk

Appendix C Brazil Ethics approval

PARECER CONSUBSTANCIADO DA CONEP

DADOS DA EMENDA

Título da Pesquisa: INTERVENÇÕES SANITÁRIAS E PREVENÇÃO DA LEPTOSPIROSE URBANA

Pesquisador: Federico Costa

Área Temática: Pesquisas com coordenação e/ou patrocínio originados fora do Brasil, excetuadas aquelas com copatrocínio do Governo Brasileiro;

Versão: 5

CAAE: 32361820.7.0000.5030

Instituição Proponente: Instituto de Saúde Coletiva

Patrocinador Principal: Wellcome Trust

DADOS DO PARECER

Número do Parecer: 5.692.139

Apresentação do Projeto:

As informações elencadas nos campos "Apresentação do Projeto", "Objetivo da Pesquisa" e "Avaliação dos Riscos e Benefícios" foram retiradas do arquivo Informações Básicas da Pesquisa (PB_INFORMAÇÕES_BÁSICAS_2004779_E2.pdf, postado na Plataforma Brasil em 22/08/2022).

INTRODUÇÃO

A leptospirose é uma das principais zoonoses em termos de morbimortalidade no mundo. Estima-se mais de 1.03 milhão de casos e 50 mil mortes anualmente, principalmente, nos países mais pobres do mundo 1–3. É uma doença causada por um grupo genético e antigenicamente diverso de 13 espécies de Leptospira e >300 sorovares. As Leptospiras patogênicas colonizam os túbulos renais de uma ampla gama de mamíferos selvagens e domésticos4 e são excretadas por meio da urina para o ambiente, onde estas persistem por semanas a meses5.

A infecção em humanos, ocorre através de contato da pele com urina animal contaminada ou mais, frequentemente, através da exposição a água, solo ou lama contaminados3,5. A leptospirose produz sintomas que variam de uma enfermidade leve, similar à gripe, a manifestações graves com risco de vida, como falência renal aguda (síndrome de Weil) e Síndrome Pulmonar Hemorrágica6, que são fatais em >10% e 50% dos casos, respectivamente7. A leptospirose era tradicionalmente considerada uma doença rural, que acometia os agricultores de subsistência e criadores de gado 3,4,8, mas emergiu recentemente como um grave problema de saúde pública

Endereço: SRTVN 701, Via W 5 Norte, lote D - Edifício PO 700, 3º andar
Bairro: Asa Norte **CEP:** 70.719-040
UF: DF **Município:** BRASILIA
Telefone: (61)3315-5877 **E-mail:** conep@saude.gov.br

em áreas urbanas pobres em países emergentes tropicais e subtropicais 9–12.

Um bilhão de pessoas no mundo vivem atualmente nestas comunidades13, onde a pobreza, condições de moradia precárias, superpopulação e falta de serviços de saneamento urbano facilitam também a transmissão da leptospirose por roedores 14,15.Em Salvador, identificamos um novo padrão da dinâmica de leptospirose urbana caracterizado por: [A] surtos ocorrendo na mesma comunidade (favela) todos os anos, seguindo períodos sazonais de maior precipitação 12,16, [B] o agente etiológico é L. interrogans sorovar Copenhageni 7,17, [C] ratazanas são o principal reservatório do patógeno 18–21, [D] deficiências de infraestrutura, como esgoto a céu aberto e sistemas de drenagem servem como rotas de transmissão 14,15,22, [E] Infecções ocorrem principalmente no ambiente peridomiciliar 22–24. Estes surtos de leptospirose, afetam também comunidades urbanas de países em desenvolvimento durante períodos de chuva sazonal 25–27 ou após eventos climáticos extremos 6,11,28,29.

Com a expectativa de crescimento da população em favelas urbanas para 2 bilhões até 202513, o número de casos de infecção de leptospirose humana tenderá a crescer. A leptospirose urbana é uma doença de cunho ambiental e, consequentemente, relacionada à problemas sanitários. Outras doenças infecciosas como as arboviroses, as diarreicas, a hepatite A, hantavirose, toxoplasmose e esquistossomose5 possuem relação com a água, o lixo e as excretas provenientes de sistemas de saneamento deficientes30. Atualmente, não há formas efetivas de prevenção e controle da leptospirose em locais com recursos limitados.

Não há vacinas seguras e eficazes disponíveis para uso humano 2,31 e o desenvolvimento de uma vacina universal e de ampla aplicação pode levar décadas. Dada a alta fatalidade da Síndrome de Weil e da Síndrome Pulmonar Hemorrágica (>10% e >50%, respectivamente3,4,32), estratégias de saúde pública para prevenir infecções são fundamentais. Estratégias de controle de roedores tem se mostrado parcialmente bem sucedidas, dado que as populações de roedores tendem a retornar ao estado original rapidamente após a ação de controle, chegando até a atingir densidades maiores 33,34. Apesar da variação espaço-temporal na infecção por Leptospira, as populações de ratos aparentam ser, geralmente, estáveis assim como a carga e excreção de Leptospira. Adicionalmente, não existe evidência de que estas intervenções de controle de roedores diminuam a incidência da leptospirose. Assim, apesar da presença do reservatório roedor ser necessária para a emergência da leptospirose urbana, não é suficiente para explicar os padrões espaço-temporais e surtos. Consequentemente, intervenções precisam focar nas deficiências de infraestruturas para prevenir ou diminuir as exposições humanas às fontes ambientais de infecção.

A incidência de leptospirose grave tem declinado na cidade de Salvador simultaneamente ao aumento do saneamento básico. Entretanto o efeito causal do saneamento básico sobre a leptospirose não foi nunca avaliado. A expansão de rede de esgoto fechado pelo governo nas favelas urbanas é, portanto, uma estratégia possível e efetiva para diminuir as taxas de infecção e casos de leptospirose em comunidades urbanas. Entretanto, o alto custo das obras, a ausência dos problemas de saúde das comunidades na agenda política e o crescimento urbano desorganizado das favelas35, a construção generalizada de rede de esgoto fechado não está no futuro próximo. A cobertura de esgoto condominial foi desenvolvida no Brasil e emergiu como uma alternativa sanitária viável e econômica. Esta alternativa deve ser uma prioridade nas favelas urbanas do país, servindo cerca de oito milhões de pessoas 36 e já tem sido implementada em menor escala em diversos países como Bolívia, Guatemala, Paquistão, Índia e Sri Lanka36. Entretanto, a efetividade da intervenção condominial na prevenção de doenças tem focado apenas em doenças diarreicas 37.

A avaliação das intervenções sanitárias é um desafio por uma gama de limitações metodológicas como [1] custo e tempo de implementação; [2] necessidade de grande6 tamanho amostral; [3] dificuldades com a aleatorização da população; e [4] fatores confundidores38. Em Salvador, identificamos quatro vezes menos incidência de leptospirose ao longo de duas décadas, coincidindo com a implementação de uma rede de esgoto pelo estado (INT-GOV) em 47% da cidade. Observamos, ainda, declínio similar na incidência em áreas da comunidade em que iniciativas com participação comunitária de baixo custo para cobrir o esgoto (INT-COM). Assim, nossa hipótese é que as INT-COM serão efetivas na diminuição do contato direto com o esgoto a céu aberto e, consequentemente, no risco da infecção por Leptospira e seus agravos.

HIPÓTESE

Hipótese 1: INT-COM e INT-GOV são efetivas na redução do risco de infecção por Leptospira e outras doenças infecciosas.

Hipótese 2: A INT-COM é efetiva em reduzir a frequência de contato humano com esgotos à céu aberto contaminado, reduzindo infestação de ratos, outros animais e a carga de DNA de patógenos no ambiente.

Hipótese 3: Áreas com INT-COM tem os mesmos níveis de queda de incidência de leptospirose que áreas com INT-GOV num período de 22 anos.

METODOLOGIA

A pesquisa proposta vai determinar o impacto das intervenções convencionais e comunitárias na prevenção de leptospirose urbana e outras doenças infecciosas. Para alcançar o objetivo 1, será desenvolvido um estudo de intervenção de mobilização comunitária para medir os efeitos das intervenções sanitárias realizadas pela EMBASA em nossa área de estudo, uma comunidade na cidade de Salvador, que foi estabelecida em 2015 para estudos prospectivos de longo prazo. Um projeto de saneamento em larga escala foi iniciado em 2018 e vai prover tubulação de esgoto para 25% da população da área até 2022. Atuaremos em conjunto com as agências governamentais e associações comunitárias para, através de mobilização comunitária, facilitar a cobertura comunitária de esgoto concorrentemente na mesma área usando uma metodologia inovadora (sistema condominial melhorado). Para isso, a EMBASA realizará intervenções estruturais no sistema de esgoto e nossa equipe, em conjunto, atuará na realização ações de mobilização e sensibilização dos moradores sobre a INT-COM.

Recrutaremos >3,600 residentes de áreas com esgotamento comum, comunitário ou sem esgotamento para definir, prospectivamente, o impacto das intervenções sanitárias seguindo uma coorte de desfechos para infecção por Leptospira e outras doenças infecciosas. Objetivo 2 caracterizaremos os mecanismos que guiarão as mudanças na exposição a Leptospira em uma sub-coorte de indivíduos selecionados do objetivo 1 e que poderá impactar em outras doenças infecciosas que possuem relação com o saneamento. Aplicaremos novas abordagens estatísticas para avaliar o comportamento do movimento com estimativas de alta precisão, ensaios inovadores para quantificação de Leptospira em reservatório ambiental e aspectos chave da infraestrutura das favelas e nas enchentes com estimativas diretas de infecção em humanos conforme o objetivo 1. Objetivo 3 vai avaliar o impacto das intervenções nos desfechos clínicos de leptospirose no nível da cidade.

CRITÉRIOS DE INCLUSÃO

1) dormem 3 noites por semana num domicílio da área;

2) 6 meses de idade;

3) concordam em participar mediante termo de consentimento escrito;

4) Inclusão no grupo da intervenção, definida por morar num domicílio que foi ligado ao novo sistema e ao tradicional em intervenções antes de primeiro de abril, início da época epidêmica de leptospirose.

CRITÉRIOS DE EXCLUSÃO

Indivíduos que apresentem condições especiais de saúde, as quais não permitam coleta de informações ou amostras biológicas.

Objetivo da Pesquisa:

OBJETIVOS GERAIS

OBJETIVO 1: Avaliar prospectivamente a efetividade de Intervenções com participação Comunitária (INT-COM) e Intervenções Governamentais (INT-GOV) na redução do risco de infecção por Leptospira e outras doenças infecciosas.

OBJETIVO 2: Determinar os mecanismos pelos quais INTCOM e INT-GOV inovadoras reduzem o contato direto com o esgoto e patógenos ambientais causadores de doenças infecciosas em favelas urbanas.

OBJETIVO 3: Determinar a contribuição das INT-COM e INT-GOV no declínio da incidência de leptospirose grave num grande centro urbano.

Avaliação dos Riscos e Benefícios:

RISCOS

O estudo apresenta riscos mínimos para os participantes. O objetivo deste protocolo consiste na utilização de uma amostra de sangue que será coletada pelos profissionais de saúde. Não será solicitada nenhuma coleta adicional. Realizaremos também, entrevista para coletar dados demográficos e de exposições às doenças infecciosas que serão realizadas bianualmente. Existem alguns riscos psicossociais associados às perguntas de coleta de dados referentes a experiências negativas de saneamento, falta de segurança ou estresse relacionado ao saneamento.

A equipe de coleta de dados conduzirá de entrevistas individuais em domicílios e em grupos focais com sensibilidade e confidencialidade. A equipe de coleta de dados será treinada em protocolos apropriados, caso os informantes fiquem angustiados ao falar sobre experiências negativas anteriores. Tais protocolos, incluirão a oferta de terminar a entrevista, perguntando ao informante se ele/ela tem um amigo ou membro da família para confortá-lo e obter orientações de um profissional de saúde mental treinado, se as respostas forem indicativas de depressão de pós- transtorno de estresse traumático.

Durante o projeto, coletaremos informações dos prontuários dos pacientes da vigilância hospitalar dos casos das doenças. Nas coletas de amostras sanguíneas, os riscos são mínimos para os indivíduos, incluindo dor, desconforto e hematomas associados com a coleta de amostras de sangue e desconforto potencial para responder a perguntas sobre as atividades diárias durante a administração do questionário de entrevista. Entretanto, salientamos que estas coletas já estão programadas na rotina do hospital como parte do protocolo de diagnóstico sendo que para este

estudo será reservada uma alíquota destas 30 coletas.
No caso das coletas no domicílio, uma equipe treinada e capacitada fará todo o procedimento. Além disso, existe o risco potencial de quebra de sigilo com relação às informações pessoais. Neste protocolo de pesquisa, os riscos são associados ao potencial de perda de confidencialidade dos dados que serão obtidos através de entrevista e revisão do prontuário médico (dados demográficos, movimentos, exposições de risco, histórico da doença atual, apresentação clínica, exame físico, e resultado de exames laboratoriais realizados) e aos procedimentos de coleta de amostra clínica.

BENEFÍCIOS
Individualmente, o projeto fornecerá conhecimento sobre os problemas de saúde associados à falta de saneamento básico, bem como fornecerá exames gratuitos aos participantes, permitindo que estes tenham conhecimento sobre suas situações específicas de saúde, em especial, aquelas doenças de interesse do estudo.
De forma comunitária, o projeto poderá ajudar a identificar a importância de prevenir, controlar doenças e criar sistemas baratos e mais efetivos para fechar esgotos e no escoamento de água.

Comentários e Considerações sobre a Pesquisa:
EMENDA 2:

Justificativa:
1) Inclusão, no instrumento original de coleta de dados, de questões referente a doença varíola dos macacos (Monkeypox). As questões a incluir serão:
a) Você conhece ou já ouviu falar da doença varíola dos macacos (Monkeypox)? (Sim; não);
b) Caso sim, saberia informar a forma de contágio/transmissão da doença? (Sim; não);
c) Nos últimos dias você apresentou ou está apresentando algum tipo de ferimento na pele (lesões, bolhas, crostas)? (Sim; não);
d) Nos últimos dias alguém que vive na sua casa ou outra pessoa conhecida apresentou algum tipo de ferimento na pele (lesões, bolhas, crostas)? (Sim; não);
e) Caso sim, que tipo de interação você teve com eles? ________________
f) Algum agente comunitário ou profissional da saúde informou você sobre a doença varíola dos macacos? (Sim; não);

2) Nos Termos de Consentimento e Assentimento Livre e Esclarecido, nomeados TCLE_responsável_legal_emanda_2022, TALE_12_17_anos_emenda2022, TCLE_grupo_focal_emenda2022, TCLE_adult_emenda2022 inclusão da informação sobre coleta de dados referentes a doença varíola dos macacos (Monkeypox).

3) Inclusão de informações sobre a doença no projeto de pesquisa.

4) Inclusão de outro método de coleta de amostras de fezes: crianças com idade entre 6 meses e 5 anos e 11 meses, além da coleta de uma amostra de fezes in natura, será solicitado ao cuidador para utilizar a técnica de coleta por meio de swab retal. Assim, foi incluído no TCLE do responsável legal pelo menor (documento nomeado TCLE_responsável_legal_emenda_2022) a seguinte informação no item Procedimentos a serem seguidos: "...e amostra de fezes por um tipo de cotonete (swab retal) para exame parasitológico do seu filho". "A coleta do swab retal será realizada por técnico de enfermagem treinado da equipe (sempre do sexo feminino), obrigatoriamente na presença de um responsável por está criança. Com a criança deitada de forma confortável, o pequeno cotonete estéril será introduzido cuidadosamente no bumbum da criança a 1-2 cm no máximo, e posteriormente inoculado no meio de armazenamento e transporte apropriado. Esse cotonete é especialmente preparado para esse tipo de coleta, não causando dor a criança".

5) Inclusão no TCLE_responsavel_legal_emenda_2022, em Riscos Potenciais da frase: "Na coleta do swab retal seu filho pode sentir apenas um leve desconforto. Informamos que são apenas alguns segundos para coleta da amostra, a qual não causará nenhuma complicação aguda ou crônica a criança".

6) Na sessão identificada "Autorização para envio, armazenamento e análise de amostras no exterior" presente no TCLE do responsável legal pelo menor (documento nomeado TCLE_responsável_legal_emenda_2022) inclusão da informação: "Além de envio para o Laboratório da Escola de Higiene e Medicina Tropical de Londres, sob responsabilidade de um dos pesquisadores do grupo de Sr. Oliver Cummings, no endereço Keppel St, London WC1E 7HT, Reino Unido."

7) Na sessão identificada "Autorização para Banco de Amostras" no TCLE do responsável legal pelo

menor (documento nomeado TCLE_responsável_legal_emenda_2022) inclusão da informação: “as amostras de sangue e fezes em desta pesquisa sejam congeladas e armazenadas” e “fezes e swab retal”.

8) Inclusão de informação no projeto: na sessão 3.1.1.6 Identificação prospectiva de outras doenças infecciosas:

a) doenças emergentes como varíola dos macacos (Monkeypox).

b) Informação sobre a coleta de fezes em crianças por meio de swab retal: “A coleta do swab retal será realizada pelos técnicos de enfermagem treinados (sempre do sexo feminino), e obrigatoriamente com a ajuda dos pais ou cuidador. Com a criança sem a parte inferior da roupa ou fraldas, em posição confortável lateral, o swab será introduzido cuidadosamente no esfíncter retal a 1-2 cm no máximo, e posteriormente inoculado no meio de transporte e armazenamento apropriado para identificação de patógenos associados a diarreias. As amostras serão analisadas através de testes de PCR multiplex.”

c) Indivíduos que no momento da coleta de amostras de sangue apresentarem feridas abertas,
semelhantes aquelas que caracterizam a doença varíola dos macacos, terão uma amostra biológica de secreção da ferida, por meio de swab, para o potencial diagnóstico da doença em laboratório, por testes moleculares, como PCR ou RT-PCR ou testes sorológicos para anticorpos específicos baseados em IgG e IgM. Todo o conjunto de equipamentos necessários para esse diagnóstico já são disponibilizados na atual pesquisa.

d) Inclusão de contexto teórico sobre a varíola dos macacos: varíola dos macacos (Monkeypox):

A Monkeypox (MPX) é uma doença infectocontagiosa reemergente de caráter zoonótico considerada endêmica na África Central e Ocidental. Causada pelo vírus Monkeypox (MPXV), um ds-DNA do gênero Orthopoxvirus, família Poxviridae, pode afetar diferentes mamíferos, inclusive humanos. A transmissão do MPVX pode ocorrer entre animal-humanos (zoonótica) e humanos-humanos (inter-humanos). A transmissão entre animal e humanos se dá através do contato com sangue, fluidos corporais, lesões epidérmicas ou mucosas de animais infectados.
Existem vários animais que são suscetíveis à infecção por MPVX, incluindo primatas não humanos, roedores e esquilos, desempenhando um importante papel na transmissão da doença.
O MPXV tem uma apresentação clínica semelhante à varíola, varicela, sarampo, infecções bacterianas da pele, sarna, alergia a medicamentos e sífilis, por isso, o diagnóstico diferencial deve ser considerado. Métodos convencionais para o diagnóstico da MPXV incluem isolamento viral e detecção de antígenos através de técnicas imunohisotológicas1. A OMS recomenda que sejam

realizados testes moleculares, como PCR ou RT-PCR para confirmação do diagnóstico em indivíduos sintomáticos que podem ser utilizados sozinhos ou em combinações com o sequenciamento. Testes sorológicos para anticorpos específicos baseados em IgG e IgM, também podem ser utilizados, entretanto, são menos específicos devido à reação cruzada por conta de vacina contra varíola e infecções por outros Orthopoxvirus.

9) No projeto, sessão 4.8 Justificativa para biorrepositório: inclusão da varíola dos macacos (Monkeypox).

10) No projeto, sessão 4.9 Envio de amostras para o exterior: Bem como, o envio das amostras de sangue e fezes para o Laboratório da Escola de Higiene e Medicina Tropical de Londres, para as análises parasitológicas.

11) Inclusão de informação no projeto: na sessão 3.1.1.1, Área de estudo, desenho e visão geral:
a) “Buscaremos selecionar 24 clusters localizados em 27 das 29 sub-bacias de MR. No entanto, por necessidade de adequações ao cronograma de trabalho da companhia responsável pela obra nas comunidades, a área de MR está sendo substituída por outras localidades nas comunidades de Nova Sussuarana, Arenoso, Jardim Santo Inácio/Mata Escura e Calabetão. As novas áreas têm sido identificadas para manter e atender a quantidade dos 24 clusters mencionados nesta proposta.”

Considerações sobre os Termos de apresentação obrigatória:
Vide campo "Conclusões ou Pendências e Lista de Inadequações".

Conclusões ou Pendências e Lista de Inadequações:
Não foram identificados óbices éticos na presente emenda.

Considerações Finais a critério da CONEP:
Diante do exposto, a Comissão Nacional de Ética em Pesquisa - Conep, de acordo com as atribuições definidas na Resolução CNS nº 466 de 2012 e na Norma Operacional nº 001 de 2013 do CNS, manifesta-se pela aprovação da emenda proposta ao projeto de pesquisa.

Situação: Emenda aprovada.

Este parecer foi elaborado baseado nos documentos abaixo relacionados:

Tipo Documento	Arquivo	Postagem	Autor	Situação
Informações Básicas do Projeto	PB_INFORMAÇÕES_BÁSICAS_2004779_E2.pdf	22/08/2022 22:26:42		Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	TCLE_responsavel_legal_emenda_2022.pdf	22/08/2022 22:23:45	Federico Costa	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	TALE_12_17_anos_emenda2022.pdf	22/08/2022 22:23:33	Federico Costa	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	TCLE_grupo_focal_emenda2022.pdf	22/08/2022 22:23:20	Federico Costa	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	TCLE_adult_emenda2022.pdf	22/08/2022 22:23:10	Federico Costa	Aceito
Solicitação Assinada pelo Pesquisador Responsável	Emendasolicitacao22082022.pdf	22/08/2022 22:22:52	Federico Costa	Aceito
Projeto Detalhado / Brochura Investigador	22_08_2022_Projeto_Lepto_emenda_agosto_2022.pdf	22/08/2022 22:19:36	Federico Costa	Aceito
Outros	Carta_Resposta.pdf	22/07/2020 09:07:39	Federico Costa	Aceito
Outros	Termo_compromisso_exterior_vedacao.pdf	22/07/2020 09:03:58	Federico Costa	Aceito
Outros	Termo_Anuencia_Universidade_Yale_Ingles.pdf	02/06/2020 22:03:49	Federico Costa	Aceito
Outros	Confirmacao_Selecao_Projeto_Wellcome_Trust_Portugues.pdf	02/06/2020 06:59:59	Federico Costa	Aceito
Outros	2020_06_01_Carta_resposta_CONEP_pendencia_documental.pdf	02/06/2020 06:58:19	Federico Costa	Aceito
Folha de Rosto	Folha_rosto_CEP_CONEP_25052020_Federico.pdf	25/05/2020 14:59:37	Federico Costa	Aceito
Outros	CV_Begon_traduzido.pdf	25/05/2020 14:07:25	Federico Costa	Aceito
Outros	Carta_Patrocinador_portugues.pdf	25/05/2020 11:59:35	Federico Costa	Aceito
Cronograma	Cronograma.pdf	25/05/2020 11:37:18	Federico Costa	Aceito
Outros	Curriculo_lattes_Diggle_traduzido.pdf	24/05/2020 19:48:35	Federico Costa	Aceito
Outros	Curriculo_lattes_Albert_traduzido.pdf	24/05/2020	Federico Costa	Aceito

Outros	Curriculo_lattes_Albert_traduzido.pdf	19:46:48	Federico Costa	Aceito
Declaração de Pesquisadores	Termo_de_Confidencialidade.pdf	23/05/2020 12:31:43	Federico Costa	Aceito
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Outros	Instrumento4_Questionarios_Placas_Rastreamento_Capturas_Ambiental.pdf	23/05/2020 12:14:28	Federico Costa	Aceito
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Declaração de Manuseio Material Biológico / Biorepositório / Biobanco	Regulamento_Biorrepositores.pdf	23/05/2020 11:50:53	Federico Costa	Aceito
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Orçamento	Orcamento.pdf	23/05/2020 11:30:47	Federico Costa	Aceito
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Situação do Parecer:
Aprovado

BRASILIA, 11 de Outubro de 2022

Assinado por:
Laís Alves de Souza Bonilha
(Coordenador(a))