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RESEARCH

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Structural Drivers of Vulnerability at the Human-Rodent Interface in the Limpopo National Park, Mozambique

Muriel Figuié[1,2*], Lourenço Mapaco[3,4], Alexandre Caron[4,5], Leonardo Hofisso[2], Iara Gomes-Jaintilal[5], and Julien Cappelle[4]

Abstract

This socio-anthropological study investigates the relations between humans and rodents in an area adjacent to the Limpopo National Park in Mozambique. Designed as part of the larger researcher on mammarenaviruses, it explores the social dimensions of the rodent-human interface, considering its spatial and temporal variability. Its results contribute to our understanding of the socio-ecological context in which new pathogens or new routes of pathogen transmission could arise and potentially spread diseases. A vulnerability-based approach was used to assess human exposure, sensibility and capacity to adapt to rodents. This study revealed: (i) Local knowledge of the dynamic of rodent populations over the last few decades, with new invasive rodents displacing native species; (ii) the social-ecological factors thought to be behind this invasion: climate change, new infrastructure (e.g., construction of a dam), new agricultural practices (e.g., cultivation of sunflowers) and policies (human resettlement); (iii) the significant impact associated with new invasive rodents (e.g., crop losses, damage to belongings), the limited capacity for individual and collective interventions to mitigate damage, and the little concern shown for rodent-related diseases; (iv) women and girls' high vulnerability to potential rodent-borne diseases due to frequent direct and indirect contact with rodents in the domestic space; and (v) the added-value of using a vulnerability-based methodology, over the more commonly used Knowledge-Attitudes-Practices (KAP) methodology, to map the structural factors shaping the human-rodent interface and its dynamic. Our findings suggest that the vulnerability-based approach offers an opportunity to better respond to the One Health claim of integrating social dimensions of health and to grasp the complexity of the social and material context in which new pathogens emerge and spread.

One Health Impact Statement

The present socio-anthropological study of the human-rodent interface comes in complement to a previous eco-epidemiological survey focusing on the rodent-virus interface. It explores the cultural and social dimensions of the interactions between rodent-human, considering spatial and temporal variability. In doing so, it contributes to the understanding of the socio-ecological dynamic, in which new viral transmission can occur and disease spread. It exemplifies, based on local knowledge, how socio-ecological changes can create new routes for the emerging virus and highlights the vulnerability of the exposed human population to address the potential related health risks. This multidisciplinary and dynamic approach of how humans and rodents interact, and how these interactions are shaped by their changing environment is a contribution to a systemic approach to health, in line with the One Health paradigm.

Keywords: animal, KAP study, One Health, environmental history, Mozambique, socio-anthropology, zoonoses

Introduction

Risks associated with emerging zoonoses have been recognised as complex and multifactorial, and focus within the biomedical sciences on their social dimensions has been intensifying.

The social dimension of health is often addressed through approaches that consider the behaviour of individuals as a risk factor and that emphasise the role of laymen knowledge, perceptions and attitudes in determining this behaviour [See for

Correspondence: [1]CIRAD, UMR MoISA, Montpellier, France. MoISA, Univ Montpellier, CIHEAM-IAMM, CIRAD, INRAE, Institut Agro, IRD, Montpellier, France; [2]Faculdade de Letras e Ciências Sociais, Universidade E. Mondlane, Maputo, Mozambique; [3]LCV, DCA, Agrarian Research Institute of Mozambique, Maputo, Mozambique; [4]CIRAD, UMR ASTRE, Montpellier, France. ASTRE, Univ Montpellier, CIRAD, INRAE, Montpellier, France; [5]Faculdade de Veterinária, Universidade E. Mondlane, Maputo, Mozambique; [6]Center of Biotechnology, Universidade E. Mondlane, Maputo, Mozambique

*Corresponding Author: Muriel Figuié. Email: muriel.figuie@cirad.fr

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example Machila *et al*. (2003); LeBreton *et al*. (2006); Barennes *et al*. (2007); Hsu *et al*. (2008); Renner *et al*. (2008); Liao *et al*. (2009); Kamins *et al*. (2014); Friant *et al*. (2015); Gbogbo and Kyei (2017); Moffo *et al*. (2020); Muriithi *et al*. (2021)]. The popularity of the KAP (Knowledge, Attitudes, Practices) tool demonstrates this focus in fields including zoonoses, particularly in research in low- and middle-income countries.

A few social science studies on zoonoses adopting a broader perspective and based on the seminal works of Farmer (1996) and Nichter (2008) contrast with this behavioural-risk approach. Beyond the cognitive and psychological drivers of human behaviour, these studies (Scoones, 2010; Figuié and Desvaux, 2015; Dzingirai *et al*., 2017; Figuié, 2018; Ebata *et al*., 2020) take into account the structural factors shaping human-animal or more broadly human-nature relationships (Sodikoff, 2015; Cabalion *et al*., 2018; Keck and Lynteris, 2018; Douno *et al*., 2021; Keck *et al*., 2021), and sometimes with a marked historical and environmental perspective (Nash, 2006).

Our paper contributes to this emerging body of work. We addressed the vulnerability of rural communities in Mozambique, living next to a national park, to risks related to rodents. In doing so, we had two main objectives.

The first was to understand what determines human exposure to rodent-borne infectious diseases. Adopting a One Health perspective, we documented these determining factors on the scale of the social-ecological system, based on local knowledge and with a particular focus on the material conditions shaping people's lives with rodents. The second objective was methodological, proposing the vulnerability-based approach as an alternative to the behavioural approach and the associated KAP tool. This objective was closely linked to the first. We argue that the KAP tool is not compatible with the One Health paradigm in regards to its poor capacity to grasp the complexity of the social and material context in which new pathogens emerge and spread.

Crucially, this study was conducted by an interdisciplinary team of sociologists (MF, LH), eco-epidemiologists (AC, JC) and microbiologists (LM, IG), and was embedded in a broader research programme. Previous to this study, three other studies were conducted by the eco-epidemiologists and microbiologists in the same area: (i) an ecological study describing the rodent community, (ii) a virological study assessing the circulation within this rodent community of pathogens (mammarenaviruses) that could be transmitted to humans, and (iii) an eco-epidemiological study identifying the ecological factors potentially associated with the transmission of pathogens between rodents and to humans. To date, only the virological study has been published (Mapaco *et al*., 2022).

The study discussed here adopted a sociological perspective and added to the previous studies mentioned above. We plan to follow this latest paper with an epidemiological study focusing on humans, in which human serological and virological data would be collected. To this end, future collaborations with human epidemiologists are in the pipeline. This study helps better understand the risks of infection experienced by different groups of humans, based on the intensity of their contact with rodents. It is hoped that together these studies will help to strengthen the intersectoral approach to health adopted by the National Health Security Plan, which was approved in November 2022 by the Mozambican Council of Ministers.

First, we expose the limits of the KAP tool in addressing the social dimensions of zoonoses. Subsequently, we present the context of our study (the periphery of the Limpopo National Park in Mozambique, and the mammarenaviruses focusing epidemiologists' attention as potentially zoonotic) and the framework developed for our analysis (vulnerability and its three components: exposure, sensibility and adaptive capacity).

In our results section, we present the socio-environmental dynamic as reported by the inhabitants of the study area, and the consequent shift in the rodent population experienced by local people as an invasion of their homes and fields. We then show the high vulnerability of these human communities to potential rodent-borne diseases as a combination of high exposure, low sensibility and reduced capacity to adapt to this invasion. In the discussion section, we consider the varying levels of vulnerability, according to gender, place and season and we underline the added value of the vulnerability-based approach in overcoming the limitations of the narrow-focused KAP tool. Our conclusion highlights the potential of the vulnerability-based approach to better respond to the One Health claim of integrating social dimensions of health.

Addressing the Social Dimensions of Zoonoses

PREVENTING THE RISK OF SPILL OVER OF MAMMARENAVIRUSES FROM RODENTS TO HUMANS

Rodents: Hosts for Human Pathogens

Rodents are a major source of zoonoses and represent a threat to potential new emerging infectious diseases (Meerburg *et al*., 2009; Han *et al*., 2015; Nieto-Rabiela *et al*., 2019). In studies on rodent-borne zoonoses, particular attention is given to *Mastomys natalensis*, a species found throughout southern Africa (Monadjem *et al*., 2015). This is because this species can host *Mammarenavirus*, an *Arenaviridae* virus family, including agents that cause severe haemorrhagic fevers with high associated mortality rates in humans (Radoshitzky *et al*., 2019). One *Mammarenavirus*, the *Lassa virus* (LASV), is responsible for thousands of clinical cases each year in West Africa (Fichet-Calvet and Rogers, 2009). A second *Mammarenavirus*, the *Lujo virus* was responsible for the outbreak in South Africa (Paweska, 2014) but its natural reservoir is yet to be discovered.

In our study area, our team had previously identified *Mastomys natalensis*, *Rattus*, *Saccostomus campestris*, *Gerbilliscus leucogaster*, *Thallomys paedulcus*, *Aethomys ineptus* and *Rattus tanezumi* (L. Mapaco, pers. comm). There is no information available on the local prevalence of rodent-borne diseases in humans in the study area. Yet *Leptospirosis*, *Toxoplasmosis*, and *Plague* have been detected in both humans and rodents in Mozambique (Nala, 2006). In addition, it was in Mozambique in 1977 that *Mopeia virus*, another *Mammarenavirus*, was first detected in *M. natalensis* (Wulff *et al*., 1977). *Mopeia virus* is described as non-pathogenic for humans (Wulff *et al*., 1977), but the risk of human infection cannot be ruled out since a study citing unpublished data indicated that antibodies to *Mopeia virus* had been detected in humans' sera in South Africa and Mozambique (Grobbelaar *et al*., 2021). The virological study performed in our study area by the team's microbiologists and eco-epidemiologists detected *Mopeia virus* in 16.9% (13.9–20.3) out of the 534 *M. natalensis* screened. The viruses detected formed a specific *Mopeia virus* sub-clade (Mapaco *et al*., 2022) different from that previously detected in Mozambique (Wulff *et al*., 1977). Our team had also hypothesised possible circulation of other mammarenaviruses detected in *M. natalensis* from neighbouring countries such as *Morogoro virus*, *Gairo virus* and *Luna virus* (Günther *et al*., 2009; Ishii *et al*., 2011; Gryseels *et al*., 2015), but none of these viruses were detected.

The Social-Ecological System

Our study site is located in the Mozambican district of Massingir, Gaza province, which neighbours South Africa. Two villages were selected, Bingo and Chibotane (Figure 1), based on the previous eco-epidemiological study of mammarenaviruses, accessibility and willingness of local authorities to participate.

The history of the area is marked by the construction of the Massingir dam on the Elephant River in the 1970s (for irrigation and hydro-electric power), the war for independence (1964–1975; Massingir was at the frontline of the resistance against Portuguese colonisers), followed by the Mozambican civil war (1975–1992)

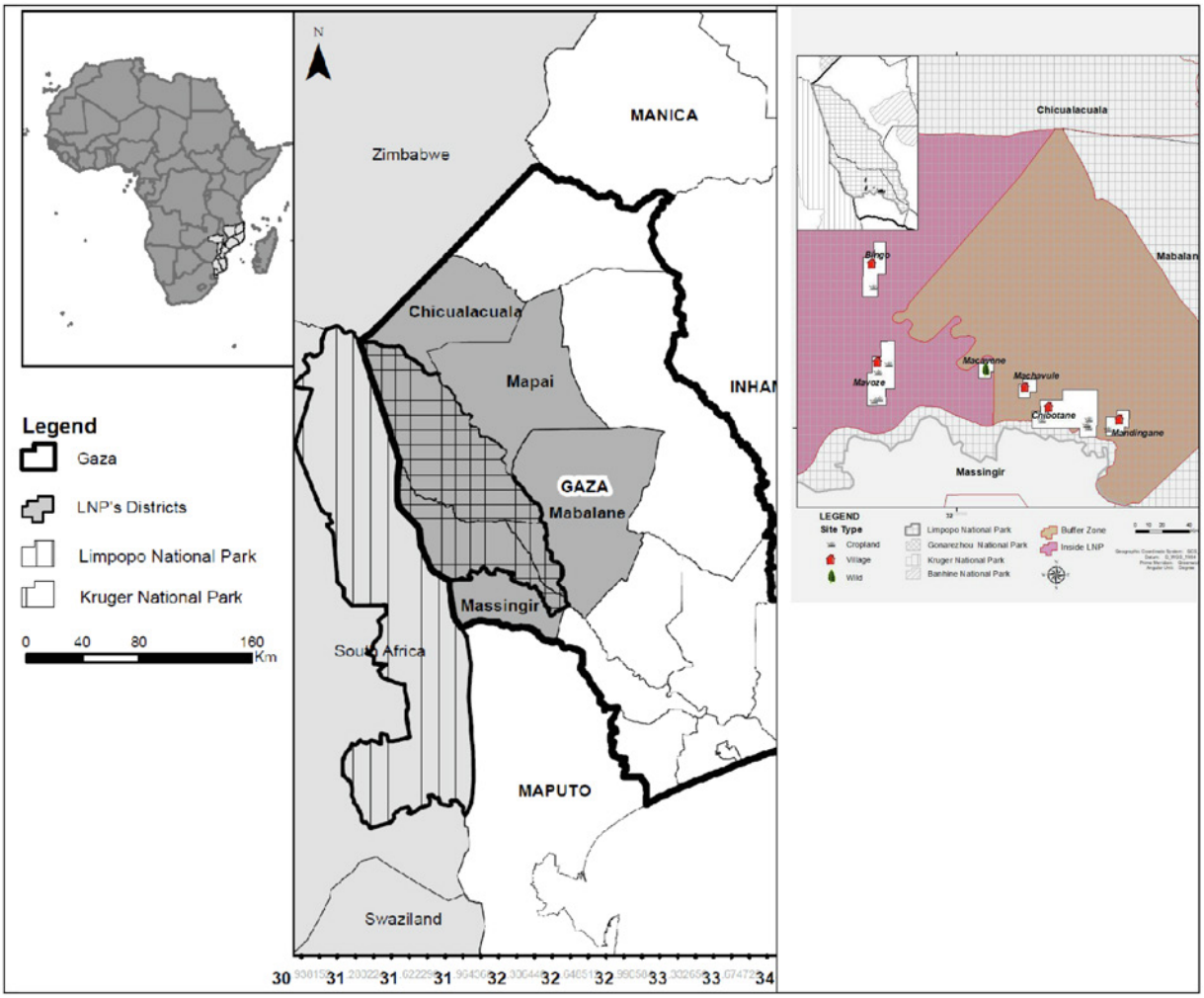

Figure 1. Map of the survey area: The villages of Bingo (inside the Limpopo National Park, LNP) and Chibotane (in the buffer zone of the LNP), District of Massingir, Province of Gaza, Mozambique. Source: Mapaco *et al*. (2022).

and the creation of the Limpopo National Park (LNP) in 2001, previously a hunting area and now part of the Great Limpopo Transfrontier Park and Conservation Area. Currently, more than 10,000 people live inside the LNP and its buffer zone. Buffer zones are transition zones between conservation areas (here the LNP) and their peripheries. In the LNP, the buffer zone was created to allow communities sustainable access to the park's natural resources, which support rural livelihoods including agriculture and livestock production. The buffer zone covers 2349 km^2 corresponding to 20.9% of the LNP (Ministerio do Turismo, 2003). As in other parts of the country, hunting activities are prohibited, including the hunting of small species like rodents. In practice, however, hunting small species is tolerated if the animals damage houses and fields and have no local value.

One of the study area villages, Bingo, is located inside the LNP and the other, Chibotane, lies in the buffer zone. Unlike Bingo, Chibotane is protected from the largest wildlife like elephants, lions and buffalos by the park fences. However, being located between two rivers, Chibotane is exposed to flooding which impacts the rodent population, as explained later in this paper. Both in the two study villages and the area as a whole, inhabitants depend primarily on small-scale agriculture and livestock farming as well as remittances from South Africa. Cultivated areas include rain-fed fields where farmers grow maize, peanuts and beans during the rainy season from November to March, and irrigated fields where mainly female farmers grow maize, beans, sweet potatoes, pumpkins and other vegetables all year round. Cattle (mainly cows and goats) are fed on fallows and natural woodland pastures under the supervision of young boys.

As a result, the study area provides an opportunity to explore a diverse range of habitats (villages, rain-fed and irrigated fields, woodlands), with different forms of human-rodent interfaces. *Mastomys natalensis* can be found in all of these different habitats, with the highest number captured in the irrigated and cropland fields and the lowest in the woodlands (Mapaco *et al*., 2022).

RENEWING THE KNOWLEDGE-ATTITUDES-PRACTICES APPROACH

The Knowledge-Attitudes-Practices (KAP) tool is a survey tool that emerged within the field of family planning in the 1950s (Cleland, 1973; Launiala, 2009). Since then, its use has extended to address a growing number of public health issues mostly in developing countries. These KAP studies aim to understand the cognitive (Knowledge) and psychological or emotional factors (Attitudes) that determine health-seeking practices and medical compliance (Practices). Since its inception, the scope of KAP surveys has gradually widened its area of application to include various issues (e.g., climate change, pesticide exposure, organic farming) including farmers' practices in relation with animal health (Lambrou *et al*., 2020; Moffo *et al*., 2020; Moutos *et al*., 2022; Oloso *et al*., 2022) and sometimes more distant issues such as electoral or purchasing behaviours (Wober *et al*., 1996; Nguyen *et al*., 2017).

This tool is often used in risk studies, to address how individuals perceive a given risk, their acceptability or aversion to that risk, and how they manage it. Today, the KAP tool is used by many

international organisations and NGOs such as the WHO, UNICEF, FAO, USAID, Médecins sans Frontières and AICF; and in interdisciplinary research, as an accessible way to include social issues, including in One Health studies (Gbogbo and Kyei, 2017; Ahmed *et al*., 2018; Jumbam *et al*., 2020; Lambrou *et al*., 2020; Delgado-Hernandez *et al*., 2021; Rana *et al*., 2021).

Despite the broadening scope and widespread mobilisation of the KAP tool, it has not been adapted to the recent advances in anthropological sociology on survey techniques, or to the numerous criticisms it has been subject to (Cleland, 1973; Moatti *et al*., 1993; Gilbert, 2001; Nichter, 2008; Launiala, 2009). Launiala (2009) explains the attractiveness of this tool by its "*characteristics such as an easy design, quantifiable data, ease of interpretation and concise presentation of results*". As such, it can address social issues and can be easily used by inexperienced researchers or experts within the social sciences.

The KAP tool emphasises cognitive deficits (Knowledge), errors of judgement (Attitudes) as well as lack of compliance with recommended behaviours (Practices), but this is to the detriment of focus on experiences, values and preferences. By focusing on cognitive deficits as the main drivers of attitudes and practices, the tool neglects structural factors limiting individual choice and places little importance on local knowledge and perspectives. It also tends to place blame on individuals, a position that has been denounced within the field of the political ecology of diseases (Farmer, 1996). Consequently, recommendations made in KAP studies narrowly focus on communication initiatives and afford little space for other levers of intervention.

In the specific case of emerging diseases, KAP studies are incapable of highlighting social and structural dynamics that may contribute to new routes of "viral traffic", to use the term coined by Morse (1995), the social inequalities of risk exposure or the potential local and collective capacity to innovate in order to face new health issues (Kleinman *et al*., 2008; Dry and Leach, 2010; Singer, 2010; Dingwall *et al*., 2013; Figuié, 2018). The continuous and widespread use of the KAP tool also demonstrates how difficult it can be to transfer advances made in one discipline to another, and how long that transfer can take.

Methodology

VULNERABILITY-BASED APPROACH

We propose here an alternative approach based on the concept of vulnerability. The concept has been mobilised in different intervention areas, such as climate change, disaster events and food insecurity (Morrow, 1999; Dilley and Boudreau, 2001; Fussel and Klein, 2006). Tools used to assess vulnerability cover a diverse range of methods (including the construction of quantified vulnerability indexes) the objective of which is to "systematically integrate and examine interactions between humans and their physical and social surroundings" (Hanh *et al*., 2009). Based on the definition adopted by the Intergovernmental Panel on Climate Change (IPCC, 2001)[1] and Hanh *et al*. (2009), we considered three components for the qualitative assessment of vulnerability: exposure, sensibility and adaptive capacity.

Exposure relates to lifestyle and practices associated with a given risk, in this case, the risk of contracting infectious diseases transmitted by rodents. The different levels of exposure are addressed depending on the spaces (home, fields…) and social categories, and considering the variability inter and intra-annual. Based on local knowledge and points of view (i.e., based on an emic perspective) but also considering the different living conditions and activities, the aim is to identify: who is exposed (e.g., men, women, children, specific professionals), when (e.g., seasonality, trends), where (e.g., in the home, fields) and, why (e.g., types of contact). We used the intensity of contacts (direct or indirect) with rodents as a proxy for exposure.

Sensibility to rodent-related risks is addressed within a broader context of human-rodent relationships. Note that, from a socio-anthropological perspective, we prefer to use the term "sensibility" rather than "sensitivity" as used by IPCC, since "sensibility" refers to an ability to perceive, while "sensitivity" refers to the quality of being sensitive. Assessing sensibility includes: (i) local knowledge about rodents and infectious diseases: ethnozoology, ethnomedicine, representations of rodents in the human-nature divide; (ii) perceived impacts of rodents on human livelihoods: benefits (e.g., meat, traditional drugs) and damages (e.g., to crops, clothes) and human health; and (iii) regimes of value that laymen mobilise in their relationships with rodents: cultural metaphors used for rodents; feelings inspired by rodents (e.g., fear, disgust, compassion).

Adaptive capacity is about the capacity to adopt practices and innovate in order to reduce perceived risks. This dimension recognises laymen as potential risk managers, and aims at identifying concrete laymen's experiences of controlling rodents and related problems including rodent-borne diseases. This includes control (individual and collective) of the rodent population, control of contact with rodents and mitigation of the negative impacts associated with the interactions with rodents.

DATA COLLECTION

Background information was first collected on the socioeconomic and agroecological context of the Massingir district. Unfortunately, as mentioned above, no sanitary information was available. A first set of 11 exploratory interviews was conducted with elders and traditional healers. One of the main objectives was to list the rodents identified by local people with their local names and to match these with their scientific names.

The local taxonomy of rodents is complex and mixes criteria of appearance (size and colour), age (juvenile *vs.* adult), habitat (house, field, woodland) and utility (e.g., edible, pest). Matching the local and scientific taxonomies was a difficult task. Scientists also recognise that species in some African rodent genera are difficult to identify and the scientific taxonomy of many groups is still not resolved (Monadjem *et al*., 2015). To identify the species present in the area, the researchers relied on morphological characteristics (Herbreteau *et al*., 2011) and genotyping. The DNA barcoding approach was used to amplify and perform the Sanger sequencing of the complete mitochondrial cytochrome b gene (CYTB; 1140 bp) (Lecompte *et al*., 2007). To overcome these difficulties, we decided to adopt the local taxonomy, to include in our study non-rodent species, such as the macroscelid *Elephantulus sp*., and to refer to them all as "rodents" and to use pictures to help clarify which animals the participants were referring to during the following discussions.

In the next step, we collected information through focus groups (FGs): 4 FGs were organised in each of the two villages (8 FGs in total) with each group containing 6 to 7 people (49 participants in total, Table 1). Based on the preliminary interviews, we hypothesised that exposure to rodents would vary for men, women and children due to their different activities, with the highest exposure among women. We then decided to conduct distinct FGs in order to facilitate the expression of each category of respondents and to focus more attention on the situation of women: 2 FGs of women, 1 FG of men and 1 FG of children were then organised in each village.

The vulnerability-based approach shaped the construction of the guide used for the interviews and the script used for the FGs, by

[1] For IPCC (2001): Exposure is the magnitude and duration of the climate-related impact such as a drought or change in precipitation, Sensitivity is the degree to which the system is affected by the exposure, whether beneficial or detrimental and Adaptive capacity is the system's ability to withstand or recover from the exposure and to seize the opportunity.

Table 1. Composition of the focus groups.

FG number	Village	Number of participants	Type of participants
1	Chibotane	6	Men
2	Bingo	6	School children (3 girls, 3 boys) aged 11 to 16 years old
3	Bingo	6	Women
4	Chibotane	6	School children (3 girls, 3 boys) aged 11 to 14 years old
5	Bingo	6	Men
6	Bingo	6	Women
7	Chibotane	6	Women
8	Chibotane	7	Women

including sequences on: lay knowledge of rodents (names, density, places, inter-intra annual dynamic of the populations, status in the culture); negative effects and benefits associated with rodents; rodent-borne diseases (etiology, symptoms, treatment); contact with rodents (alive or dead) or their excretions and fluids (who, when, how?); practices (individual, collective) aimed at limiting contact with rodents and rodent damage (mitigation/adaptation). FG scripts were adapted to the different activities addressed by the groups: i.e., housekeeping, management of the granaries, agricultural field work, hunting, herding, wood and wild fruit gathering.

Participants were recruited thanks to help from local authorities, female leaders, farmer associations and, for the FGs with children, school teachers. Discussions were conducted in the local language, Xichangana. A representative of the local authority introduced each discussion in order to inform the participants about the purpose of our research and confirm their willingness to participate by signing a consent form. The moderator tasks were shared between the Xichangana speakers (LM, LH) with simultaneous translation in Portuguese for the other members of the team. FG discussions with the adults lasted between 1.5 and 2 h and around 1 h with the children. Interviews and FG discussions were recorded. Discourse analysis was manual, and organised according to the topics that emerged during the following sections. The quotations taken from interviews and FGs are translated here into English.

We used a triangulation methodology. This means that one piece of information must be collected from more than one source (FG members or interviewees) to be considered relevant. At the end of each FG, if an important piece of information collected previously has not yet been corroborated, we asked questions to see if it could be confirmed or to discuss potential divergences in opinions or contradictions. We did not consider information provided by only one respondent. For example, we did not include in our analysis three local names of rodents mentioned by one respondent, because nobody else cited these names. However, if a piece of information only mentioned by one respondent seemed particularly relevant and important, we included it but specified that it was "according to one respondent". No new information arose in the last set of FGs, indicating that the research process had reached saturation.

Our team also prepared an event: "The day of the rats" (O dia dos ratos). After data collection, participants and other members of the community were invited to a small exhibition prepared by one of the team members (IG), which included pictures of rodents, traps and rodent-proof granaries from around the world. One member of the team was charged with setting up the exhibition, receiving visitors and answering their numerous questions. Cartoons related to rodents were shown for the children ("Ratatouille" and "the Pied Piper"). This event was a way to provide information on rodent-borne diseases and examples of protection from rodent damage. It was also a way to thank children for their cooperation by putting on some entertainment for these isolated villages.

Results

RODENTS (AND RELATED SPECIES) IN THE LOCAL TAXONOMY

"Condjo" is a generic term used locally to refer to rodents found in homes and granaries. Respondents make the distinction between big Condjos (also named "ratazana") and smaller ones. According to the discussions with respondents using pictures, this group includes *Rattus sp., Mastomys natalensis, Mus musculus*. They are the most common rodents in the area according to the respondents (Table 2). "Mbeva" is a generic term used to name rodents found in crop fields. According to the respondents, this group includes *Mastomys natalensis, Thallomys paedulcus* and *Aethomys ineptus.*

This revealed that species considered different by the researchers (*Mastomys natalensis, Thallomys paedulcus* and *Aethomys ineptus*) are referred to by the same name in local taxonomy: Mbeva. In addition, one species for the scientists, *Mastomys natalensis*, is referred to by different names in local taxonomy, depending on its habitat: small Condjo when found in a home, and Mbeva when found in fields.

The situation is simpler when it comes to rodents and related species found in woodland areas. Respondents differentiate between Vondo (cane rat/*Thryonomys swinderianus*), Fucuzane (mole rat/*Cryptomys hotentottus*), Nungo (porcupine/*Hystrix africaeustralis*), Jengwa (South African springhare/*Pedetes capensis*), Matxigane (squirrel, *Paraxerus cepapi*), Nadvitane (dormouse/*Graphiurus murinae*) and Matoxo (bushveld gerbil/*Gerbilicus leucogaster*). We had difficulty identifying other local names that were cited: Maduro (probably the elephant shrew, *Elephantulus sp*.) and Sengane (probably the fat mouse, *Steatomys pratensis*), both of which were said to be very common in homes, fields and woodlands. We did not record any mention of the potential presence of *Saccostomus campestris* (pouched mouse) during the FG discussions, despite high numbers being detected in the ecological study. Similarly, the FG members did not cite the presence of *Mastomys natalensis* (Natal multimammate mouse) in woodlands, despite *Mastomys natalensis* being found in the ecological study in the villages and crop fields, and also to a lesser extent in woodlands.

EXPOSURE: INVASION AND INEQUALITIES

Condjos are depicted as invasive rodents whose population has been increasing in homes and granaries since the 2000s, particularly the big Condjo (*Rattus* sp./Black rat or Asian rat). On the other hand, woodland rodents (Vondo/*Thryonomys swinderianus*/cane rat; Fucuzane/*Cryptomys hotentottus*/mole rat; Nungo/*Hystrix africaeustralis*/porcupine; Jengwa/*Pedetes capensis*/South African Springhare) are considered native and their population is said to be decreasing. Due to their role in domestic work, women and girls are considered to have the highest exposure to contact with rodents, mainly through their indirect contact with Condjos.

The Socio-Environmental History of Rodents: The Story of an Invasion

Data collected from different respondents allowed us to trace the evolution of the area's rodent population over the last few decades. In the 1950s and 60s, there were said to be high populations of rodents in the area. Unlike today's rodents, however, they lived in woodland areas. Their presence was valued as a source of bushmeat (such as Vondo/*Thryonomys swinderianus*, prized for its tasty meat). It is thought that changes in the local climate, marked by higher temperatures and lower rainfall, have contributed to the

Table 2. Rodents and related species cited in the study area. Laymen and expert taxonomy.

1. Places	2. Local names	3. Scientific and common names	4. Respondents' comments
Villages (homes and granaries)	Big Condjo	*Rattus rattus*/Black rat *Rattus tanezumi/Asian rat*	Inedible invasive ("exotic" species) common
	Small Condjo	*Mastomys natalensis*/Natal multimammate mouse *Mus musculus*/House mouse	Inedible Invasive in villages, migrating from field crops (*Mastomys sp*.)
Fields	Mbeva	*Mastomys natalensis*/natal multimammate mouse *Thallomys paedulcus*/Tree rat or Acacia rat *Aethomys ineptus*/Tete veld rat	Bushmeat
Woodlands	Vondo	*Thryonomys swinderianus*/Great cane rat	Bushmeat* forbidden to hunt
	Nungo	*Hystrix africaeustralis*/Porcupine	Bushmeat, medicine forbidden to hunt
	Jengwa	*Pedetes capensis*/South African springhare	Bushmeat* forbidden to hunt rare
	Fucuzane	*Cryptomys hotentottus*/Mole rat	Traditional medicine rare
	Matxingane	*Paraxerus cepapi*Squirrel	Bushmeat
	Ndavitane	*Graphiurus murinae*/African dormouse	Traditional medicine
	Matxoxo	*Gerbilicus leucogaster*/Bushveld gerbil	
Mix	Maduro	*Elephantulus* sp. *Elephant shrew*	Common
	Sengane	*Steatomys pratensis*/Fat mouse	Bushmeat* (depending on where it is found) common

*Respondents mentioned that authorities had banned hunting of these species, but said they were still part of the local food culture.
Data in columns 1, 2, and 4 are based on FGs and interviews; and in column 3 on the expertise of the scientific team.

observed decrease in rodent populations. These woodland rodents were replaced by more invasive rodents. Indeed, in 1972, with the construction of the dam of Massingir, big trucks arrived in the area bringing with them big black rodents (Big Condjo most probably *Rattus rattus)*, the population of which rapidly proliferated. In the same period, the human habitat changed from scattered households to villages. These changes were driven by population displacement imposed by the creation of the dam as well as policies introduced by the Frelimo Party, which was ruling the area at the time and headed the movement that resulted in Mozambique's independence in 1975. Frelimo decided to gather households for their protection (and control) in a process known as "villagisation".

From then on, populations of these bigger invasive rodents (i.e., big Condjo, *Rattus sp*.) increased progressively in the two villages, and populations of rodents from the crop fields like Mbeva also began to increase (*Mastomys natalensis*, *Thallomys paedulcus, Aethomys ineptus?*) and to colonise households (*Mastomys natalensis*). Moreover, according to one of the respondents, the government promoted the production of sunflowers, which would have encouraged these new invasive rodents. Yet, it was not until the 2000s that the rodent population really started to increase dramatically, in particular in Bingo. Following a serious flood in 2000, trucks arrived with food aid but also with more "big black rodents" (probably *Rattus tanezumi* only found in Bingo). The invasive rodents already present in the area moved from lower to higher areas, such as Bingo (Chibotane was said to be less affected), invading fields and most of the houses. These rodents established themselves definitively in this favourable environment, in houses and granaries. More flooding in 2013 intensified this process. The rodents that invaded houses from 2000 onwards are described as big, frightening and strange:

"They' big, scary rodents, we don't have any poison to kill them."

"We have rodents in the field, in the house. But the rodents we have in the village are scary rodents."

If floods pushed "new" commensal rodents into the villages, periods of drought in 2015 and 2019 would have significantly affected the "local rodents", such as Vondo (great can rat) and Jengwa (South African springhare) more dependent on natural vegetation. These two trends help to explain the shift in rodent populations, mainly benefiting the *Rattus sp*.

Two women in one of the FGs said the increasing population of rodents in the fields and houses was because of an abandonment of tradition: "The rodents started punishing us in the 2000s". With the development of "the religion" (meaning Christianity, as opposed to Animism), people were neglecting tradition. They preferred to go to church and no longer practiced the Upaxa, a traditional ceremony aimed at preventing animals like rodents but also monkeys and elephants from destroying their crops. Surprisingly, events that might have had an impact, such as the creation of the LNP, the development of irrigation schemes in Bingo and the potential increase of consumption of rodents during periods of food shortage like during the war, were not mentioned.

Exposure to Rodents: A Gender Focus

FG discussions also allowed us to identify people, places and activities contributing to contact with rodents, based on how humans and rodents share common spaces. Participants of the FGs reported regular contact (direct or indirect) with rodents,

on the same day of or within the week leading up to the FG discussion. When we asked participants who they thought was most exposed to direct or indirect contact with rodents, most said women and girls. Indeed, activities differ among women, men and children, and so too does the potential for contact with rodents. Throughout the year, women and girls spend a lot of time at home, performing domestic tasks. In particular, girls are regularly sent into the granaries where rodents are said to be numerous.

"The people who are most exposed to rodents are the women because they look after the granary, then the girls because they help the women to look after the house."

"The rats come down into the kitchens. It even seems that they work together with the women."

"The girls are more exposed than the boys because they work in the granary and in the kitchen while the boys go to pasture."

Even if it was not highlighted directly by the respondents, we could also hypothesise that hunters, cattle herders (in particular young boys) and traditional healers ("curandeiros") are likely to be more exposed to woodland rodents since hunters and herders catch them for bushmeat (Vondo/cane rat, Fucuzane/mole rat, Nungo/porcupine, Jengwa/South African springhare, Matxigane/squirrel), and traditional healers for use in medicines (Fucuzane/mole rat, Nungo/porcupine, Ndavitane/African dormouse) based on rodent flesh, skin and faeces.

Different Types of Contact

Contact with rodents can be direct or indirect, intentional or unintentional. The main reported contact is through rodents spoiling food (in the kitchen or in granaries) and clothes, with their saliva and paws.

Rodents are said to take advantage of any moment of inattention to steal food from kitchens, in which case the top part of the meal is generally discarded and fed to dogs or cats. Numerous traces of urine and faeces can be found in food stored in the granaries as well as in beds, blankets and clothes. Women and girls are the most exposed since they are the ones in charge of cleaning, including collecting faeces directly with their hands. More direct contact occurs when women try to trap the rodents in their houses: they beat them with a piece of wood and pick the dead animal up by the tail.

The presence of fleas is attributed to rodents (and sometimes chickens), and exposure to fleas is said to be a significant problem, in particular in Bingo where respondents reported periods where they have to sleep outside their homes to escape from the fleas. Rodent bites are rare and mainly affect children playing with dying rodents, or people going to bed without washing hands of the smell of food, which would attract the animals. Rodents are also said to bite dead bodies exposed before the funeral. Some species found in woodlands (mainly Vondo/cane rat, Nungo/porcupine, Matxigane/squirrel) serve as bushmeat but this consumption is said to be decreasing due to the decline of populations of edible species and the ban on hunting controlled by the park's authorities.

"When the babies end up crying, without us knowing what's happening, it's because of rodents chewing their fingers."

"Rodents bring irritating insects through the skin; we can't sleep; we need to sleep outside because there are insects inside."

"Fleas come with the rodents. As long as rodents exist, fleas will exist. Getting rid of rodents can help us get rid of fleas".

SENSIBILITY: RODENTS AND FOOD

Not all respondents were able to name the different rodents they encounter, but everyone expressed significant concern about the extensive damage caused by the rodents living in the villages and the fields. FGs with the women emphasised damage to homes and granaries, while the men highlighted damage to the cultivated areas. On the other hand, rodents found in woodlands were perceived positively since they can be useful to humans as bushmeat or traditional medicines. As one respondent put it: "The place of rodents is in the woodland."

A Threat to Food Security

Rodents living in human settings are perceived very negatively. The big rodents present inside the houses are described as scary, in particular by women, the most exposed group. Rodents obviously bring with them numerous nuisances but why they inspire fear is unclear. Rodents are perceived above all as a threat to food security. First, they eat the seeds stored in the granaries and newly sowed seeds in the fields. They consume crops during the pre-harvest period, the food stored in the granaries and cooked meals in the kitchen. They also kill the chicks in the backyard. Respondents estimated they lost up to 50% of their food to rodents. Moreover, rodents destroy and spoil clothes, blankets, beds and sometimes even banknotes. They dig holes inside the house in which other animals like snakes can then live or nest.

"While we are eating, the rodents are also eating. If there were no rodents, our crops could feed us for a year. But when there are rodents, our crops cannot last up to a year."

"The chickens in our houses […] the rodents kill our chickens."

"Our coexistence with rodents has been very difficult. Our complaint with rodents is that they eat the food we cook in our houses, as well as the food cultivated in our fields."

… and Potentially to Food Safety and Health

When asked about rodents and diseases, the respondents' first thought was of Fucuzane the mole rat's used in the traditional pharmacopeia. Participants were not able to name any diseases transmitted by rodents to humans, and generally showed limited and confused knowledge of zoonoses: one respondent cited a disease transmitted by dogs, without naming rabies explicitly; another mentioned the risk of drinking milk from a cow with red urine (the team's veterinarians identified this as a potential symptom of Redwater disease, a tick-borne disease also known as Babesiosis); and another mentioned an unnamed disease sexually transmissible by monkeys. Nevertheless, respondents considered that rodents spoiling food could contaminate it with "poison" or unknown diseases. But no one reported any personal experience of health problems related to rodents.

"We have to dump the food for fear of diseases. We don't know what the diseases are."

"Sometimes when we have food and the rodents come and eat it, we have to throw away the top part because it contains poison."

Benefits Associated with "Woodland Rats" as a Source of Bushmeat

Benefits associated with rodents are limited to bushmeat and traditional medicines. Fucuzane is the word used to describe a rodent species (the mole rat), a type of wound "with blood and water" on the leg or foot that does not heal easily, and also the traditional drug prepared with the flesh of the rodent to heal this kind of wound. Nungo (porcupine) is used for treating "fire of the night" (probably herpes zoster), to cure wounds caused by bewitching and vomiting. Ndavitane (African dormouse) can also be used to increase the skills of hunters and football players.

"I used to eat rodents […] but the ones that exist today are no longer edible."

"We use Fucuzane to cure a disease that comes out in a person's foot… we kill the Fucuzane, then we skin it, put it on a stick and then bake it dry. When someone gets sick, we burn the Fucuzane and put its ashes on the wounds."

ADAPTIVE CAPACITY: A FEELING OF POWERLESSNESS

Respondents agree on the need to reduce the number of rodents in homes and in the cultivated fields. However, there is a mismatch between the intensity of complaints against rodents found in these areas and the paucity of measures taken to control them. Adaptive capacity to face the growing nuisances brought by rodents is limited.

Individual Measures in Houses and Granaries

Different measures to control rodents are reported by the respondents, who also underlined their limited effectiveness, high cost and side effects. Traps or poison are only available in Massingir city (35 km from Bingo and 18 km from Chibotane, accessible via a sandy track road and transport is considered expensive). These solutions are sometimes used in households and granaries, but are said to be ineffective: the rodents are too big for these traps and the rodenticides just "fatten" them. Moreover, people are reluctant to use rodenticides for fear that other animals like chickens or cats or even children could consume them. Some households keep cats in their granaries, but they are difficult to come by and, moreover, considered ineffective since rodents can be bigger than the cats and are even capable of eating kittens.

Inside homes, throwing boiling water into the tunnels excavated by rodents is seen as a more effective option. Maintaining a clean house is also considered as a way to control the rodent population. Surprisingly, the architecture of the local granaries did not include any protection against rodents, as may exist in other countries. House and granary roofs made of zinc, not straw help better control the rodent population, according to respondents, since straw roofs are fresh and can host rodent nets all year round. However, zinc roofs are also considered too expensive.

Attempts at Collective Action in Cultivated Areas

Measures to control rodents are undertaken on an individual level, but participants emphasised the need for collective action in the fields. However, there have so far been few attempts at collective action. As mentioned above, in the past, people would attend a traditional ceremony believed to protect crops from rodents and other predators like monkeys and elephants, but this tradition is disappearing. Traps with bait are sometimes used in the fields, but, as one respondent said, since only a few farmers use traps, he fears they attract rodents in from other fields. Some burn the fields to clear them of rodents and other pests.

Any financial and technical support is expected to come from agricultural extension services, not health services, because rodents are mainly perceived to be a threat to agriculture and food security rather than human health. In 2019, a group of farmers purchased the pyrethroid-based product Tamaron and tried using it against rodents. Despite being an insecticide-acaricide, the product proved to be very effective, according to the respondents. However, it was too expensive for them to repeat this method.

Farmers living in or around conservation areas generally expect compensation from the park authorities for any damages to their crops caused by wildlife. However, respondents did not consider the possibility that the LNP could help them to control rodent populations. This demonstrates that respondents do not consider rodents to be wildlife and that their multiplication was associated with a process of anthropisation, as explained above, rather than their proximity to a conservation area.

"We have no way to get rid of them."

"*Sometimes we put down rodenticides, but the rodents don't eat them, and if they do, they don't die, they just get fat."*

"We don't use rodenticides in our houses because the cats will end up dying, and when rodents eat the rodenticide, they can then eat the chima (traditional meal made of maize). Then it can also cause problems for us."

Discussion

This study had two objectives: (i) to understand what determines human exposure to rodent-borne infectious diseases; and (ii) to use a vulnerability-based approach, as an alternative to the KAP behaviour-based approach, to highlight these determinants, their dynamic and variability.

VULNERABILITY TO RODENT-BORNE INFECTIOUS DISEASES

Mastomys natalensis (Natal multimammate mouse) has been identified by scientists as a reservoir of mammarenaviruses and a potential human health threat. To study the social factors that might influence the emergence and spread of rodent-borne diseases, we used a vulnerability framework based on three components: exposure, sensibility and adaptive capacity. Our research reported frequent direct and indirect contact with rodents, particularly among women and girls in the domestic space, low sensibility towards rodent-borne diseases, but high sensibility to a perceived rodent invasion; and a reduce adaptative capacity.

People living in Bingo, and in particular women and girls, are more exposed to contact with rodents and potential rodent-borne zoonoses than people from Chibotane and men and boys generally. A study in Nigeria also indicated that women and children were more exposed to *Lassa virus* infections due to high involvement in domestic activities (Izah *et al*., 2022). Unfortunately, there is no available serological data on exposure to pathogenic rodent viruses, such as mammarenaviruses or Leptospirosis, in our study area, to help us cross-check our results.

Assessing the seasonality of this exposure is complex. Based on the previous ecological survey and studies such as Massawe *et al*. (2011), populations of *Mastomys natalensis* are at their highest during and after the rains. However, our study showed that when it comes to contacts between humans and rodents, there is no clear seasonal pattern: many factors affecting the frequency of contacts were mentioned such as boys spending more time chasing rodents and girls spending more time working in the kitchen during school holidays leading to their increased exposure. Most importantly, respondents mentioned high numbers of rodents within houses and granaries during dry seasons as resources outside become scarce. This was confirmed in Guinea by Fichet-Calvet *et al*. (2007) who reported Lassa fever cases all year round, and by Clark *et al*. (2021) who cite household contact with rodents in households during the dry season as the main factors that sustain *Lassa virus* transmission between rodents and humans.

Regarding sensibility, people from Bingo and Chibotane did not know about rodent-borne diseases and therefore do not feel exposed to their threat. If cases of *Leptospirosis* are likely, according to experts, our interview with the head of the local hospital in Massingir confirmed that cases of Leptospirosis are probably misdiagnosed and treated as malaria by modern or traditional medicines. There are currently no available means of medically diagnosing rodent-borne diseases, and the population is also 'culturally naïve' to them (we use this phrase here in reference to the medical expression, and not as a value judgement).

In contrast, rodents are very visible. How they are perceived differs widely depending on where they are found. They are not perceived to be a source of infectious diseases, but when Condjos are found in houses, they are seen as a hygiene problem and the cause of damage. When the same animals are found in fields, their name changes from Condjo to Mbeva and they are perceived more positively as a potential source of bushmeat. This contrasting perception between home and bush rodents was highlighted by Douno *et al*. (2021) in their study of young Guinean hunters' exposure to Lassa fever. As argued by the anthropologist Mary Douglas in her seminal work: "Dirt is matter out of place" (Douglas, 1966/2002). Rodents belong to this category of the so-called "trash animals" (Nagy and Johnson II, 2013), transgressing the boundary between biodiversity and pest, in particular in buffer zones.

Regarding adaptive capacity, our study cannot anticipate how the communities in the study area would respond to a potential new emergence (*Mopeia virus*, for example) because of the invisibility of the infectious threat linked to rodents. Community- and household-led responses are important factors in the spread of diseases since they shape the dynamic of an epidemic, and yet are too often neglected within epidemiological models (Funk *et al*., 2010). But our study shows that while the communities are sensible to the rodent invasion, locally-available resources to control it are limited. Interestingly despite important damages, rodent management was not a source of social conflict, contrary to what has been reported in other contexts (Lauret *et al*., 2020). Measures are taken at an individual level, but the participants in our study recognised the need for collective action in cultivated areas, which could be led by farmer associations and/or local authorities. Women are the most concerned about the presence of rodents in the domestic area, but they may not be the decision-makers when it comes to buying traps or rat poison or building rodent-proof granaries.

If a rodent-borne disease were to emerge there would be very little means, individual or collective, to control the rodent population, and such a disease would spread easily within this context of poor access to medical care. Our findings indicate the high vulnerability of these communities, with women and girls most at risk.

METHODOLOGICAL INPUTS

In our preamble, we argued that the KAP tool is not capable of contributing to the ambition of the One Health paradigm due to its poor grasp of the complexity and dynamic of the social context in which pathogens emerge and spread.

The vulnerability-based approach enables structural factors, local knowledge and learning processes from past experiences to be taken into consideration, rather than simply measuring cognitive gaps. In the present study, we started from the initial hypothesis that respondents were well-informed actors, able to document our research, as opposed to simple subjects of research like the host or reservoir of diseases. The respondents had no known experience of rodent-borne diseases, but rich knowledge of rodents and their ecology. Our study highlights the complexity of the rodent-human interface, documenting the changes in spatial connections, and the interactions between micro and macro factors. Research into social factors influencing the human-animal interface (and the potential spread or emergence of disease) cannot focus solely on individual behaviour but must also address the full scope of the social-ecological system with its local variations (Zinsstag *et al*., 2011). That is what is suggested by Nichter (2008) when he argues for a new generation of health social science research that serves a global health agenda. Rather than providing a static description, the vulnerability-based approach enables to trace the dynamics of the rodent population from the 1950s and to document the various events that have shaped the human-animal interface, particularly climatic (floods, droughts) and anthropogenic (new infrastructures or crops, "villagisation") events.

The KAP tool encourages focus on communication/education/awareness-based interventions, which make up only a small part of the response needed to address social issues related to infectious diseases. This would not be enough to solve the problem of rodent invasion or poor access to health care. The vulnerability-based approach offers a perspective, documents social inequalities in risk exposure and thus opens up space for a biopolitical analysis of health as suggested by Nichter (2008).

There are two main limits to the reliability of our collected data. First, given the context of the National Park and the ban on hunting, our data on risk exposure related to rodent hunting and consumption may not reflect reality. However, as the district of Massingir is well-known for criminal poaching and its links with the international traffic of endangered species like rhino horns, hunting rodents may be seen locally as comparatively harmless and easier to report. Secondly, when we conducted our survey in April 2021, it was the low season for agricultural work. Men's exposure to rodents in irrigated areas may therefore be underreported by respondents.

Conclusions

Our study contributes to understanding changes in the human-rodent interface at the scale of the social-ecological system. It illustrates the value of multidisciplinary collaboration to highlight socio-ecological dynamics in which new patterns of viral traffic can occur and diseases spread. From a social sciences perspective, this article shows the limits of approaches that are centred on individual perceptions and behaviours, and the added value of addressing the cultural and social dimensions of the human-animal interface over time and space. Additionally, instead of focusing on knowledge gaps and perception biases, it shows how local knowledge can be a rich source of information for documenting local environmental history. Accordingly, it demonstrates that even in a fairly remote location, such as at the border of a conservation area, anthropogenic factors can significantly influence rodent population dynamics and human susceptibility to rodent-borne diseases. Capturing these dynamics, based on the lived experiences of potentially exposed people, is essential when studying emerging diseases.

As mentioned in the introduction, this study is embedded in a broader research programme, and is expected to be followed by an epidemiological study with the collection of serological and virological data on humans. The present study will support the sample strategy (who, when). In return, the epidemiological study on humans will help document the link between exposure to rodents and exposure to their pathogens.

The proposed approach is not intended to replace in-depth ethnographic studies, but for non-social scientists currently using the KAP tool, it may offer an alternative framework in which to address the social complexity of zoonotic disease emergence and circulation. The vulnerability-based approach is flexible enough to be adapted to various contexts. Further work is required to provide it with some of the characteristics that made the KAP tool so successful: "easy design, quantifiable data, ease of interpretation and concise presentation of results […]" (Launiala, 2009).

As previously mentioned, this vulnerability-based approach is already being used in other sectors focused on issues such as climate change, natural disasters and food insecurity, sometimes associated with a quantified assessment and always with the same ambition to "systematically integrate and examine interactions between humans and their physical and social surroundings" (Hanh *et al*., 2009). The approach could help build a community of practices addressing health issues in an integrated way (Singer, 2010; Whittaker, 2020). It could contribute to a much needed alignment of One Health ambitions and research practices.

CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

ETHICS STATEMENT

A credential to work in the Limpopo National Park was obtained from the Mozambican National Administration for Conservation Areas (Credential Nr. 1/02/2021). No personal data was collected. Prior consent forms were signed by participants of the FGs (in the case of children, the consent form was signed by a responsible adult). Due to the on-going Covid-19 epidemic, FGs were held outside, except for the children who remained in classrooms, and always maintained distance between participants. All participants were given a mask and had hands sanitised.

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AUTHORS’ CONTRIBUTIONS

As an interdisciplinary collaboration, the whole team designed the objectives and hypotheses of the study. The eco-epidemiologists provided the list of rodent species present in the area (LM, IG), prepared pictures of these species (adults and juveniles) as aids in our discussions with the community (IG); and helped to match the scientific taxonomy with the local names (LM, IG). The team’s sociologists (MF, LH) designed the methodological tools (vulnerability-based approach, guidelines for interviews and focus group discussions). The whole team was involved in data collection. One of the sociologists (MF) designed the article focus and structure and prepared the first draft of the manuscript, including data processing, while the other authors commented on the initial and subsequent drafts and contributed to this final version.

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