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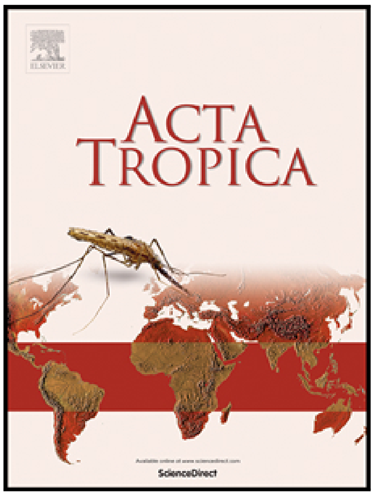

Community-based symptom reporting among agro-pastoralists and their livestock in Chad in a One Health approach.

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PII: S0001-706X(24)00051-2
DOI: https://doi.org/10.1016/j.actatropica.2024.107167
Reference: ACTROP 107167

To appear in: *Acta Tropica*

Received date: 2 October 2023
Revised date: 2 February 2024
Accepted date: 28 February 2024

Please cite this article as: Camille Doras , Ranya Özcelik , Mahamat Fayiz Abakar , Ramadan Issa , Pidou Kimala , Soumaya Youssouf , Isabelle Bolon , Salome Dürr , Community-based symptom reporting among agro-pastoralists and their livestock in Chad in a One Health approach., *Acta Tropica* (2024), doi: https://doi.org/10.1016/j.actatropica.2024.107167

Highlights

- Remote agro-pastoral communities in Chad are excluded from organized disease surveillance systems.
- Their traditional way of life, close to their livestock, makes them particularly vulnerable to zoonoses.
- One Health syndromic surveillance could help to improve the monitoring of epidemiological events in humans and animals living in these communities.
- Based on a retrospective survey, we collected relevant information on the health of households composed of livestock and people.
- We demonstrated the relevance of community-based health information reporting, paving the way for future real-time One Health syndromic surveillance in Chad

Title

Community-based symptom reporting among agro-pastoralists and their livestock in Chad in a One Health approach.

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Abstract

One Health Syndromic Surveillance has a high potential for detecting early epidemiological events in remote and hard-to-reach populations. Chadian pastoralists living close to their animals and being socio-economically unprivileged have an increased risk for zoonosis exposure. Engaging communities in disease surveillance could also strengthen preparedness capacities for outbreaks in rural Chad. This study describes a retrospective cross-sectional survey that collected data on clinical symptoms reported in people and livestock in Chadian agro-pastoral communities. In January-February 2018, interviews were conducted in rural households living in nomadic camps or settled villages in the Yao and Danamadji health districts. The questionnaire covered demographic data and symptoms reported in humans and animals for the hot, wet, and cold seasons over the last 12 months. Incidence rates of human and animal symptoms were comparatively analyzed at the household level. Ninety-two households with a homogeneous socio-demographic distribution were included. We observed cough and diarrhea as the most frequent symptoms reported simultaneously in humans and animals. In all species, the incidence rate of cough was significantly higher during the cold season, and diarrhea tended to occur more frequently during the wet season. However, the incidence rate of cough and diarrhea in animals did not predict the incidence rate of these symptoms in humans. Overall, the variations in reported symptoms were consistent with known seasonal, regional, and sociological influences on endemic diseases. Our retrospective study demonstrated the feasibility of collecting relevant health data in humans and animals in remote regions with low access to health services by actively involving community members. This encourages establishing real-time community-based syndromic surveillance in areas such as rural Chad.

Keywords:

Chad, agro-pastoralists, zoonoses, syndromic surveillance, One Health.

1. Introduction

There is a crucial need to better prevent and respond to epidemics of animal origin, illustrated by ongoing negotiations on the World Health Organization pandemic treaty at the time of writing (1). We know that up to 75% of all emerging infectious diseases are zoonotic (2,3) and that in 2012-2022, there has been a 63% increase in zoonotic epidemics in Africa compared to 2001-2011 (4). Research on the early detection of infectious diseases in animals and humans and capacity building around disease surveillance in low- and middle-income countries (LMICs) are two key pillars to answer this need. In LMICs, disease surveillance systems are poorly functional or limited to urban areas, excluding remote and underserved communities (5). Disease surveillance in rural communities and livestock is also essential because of the increasing risk of zoonotic spillover to large urban areas (6).

Pastoral populations are particularly vulnerable to under-reporting of infectious diseases because often excluded from health services (7). Potentially easier to implement, syndromic surveillance, which relies on pre-diagnosis information, could be relevant in such contexts (8,9). Syndromic surveillance using the One Health approach, *i.e.* integrating the human, animal and environmental health sectors, could even bring added value in improving these health challenges (10,11). Community-based surveillance is defined as "the systematic detection and reporting of events of public health significance within a community by community members" (12–14). In rural and pastoral areas, such engagement, valuing the knowledge and perceptions of community members for themselves and their livestock, is critical to improving human and animal disease surveillance (15–17). Community-based syndromic surveillance using a One Health approach began to develop in Africa more than a decade ago, notably through smartphone applications that transmit and analyze health data from pastoralists and their animals in real-time (16–19). However, limitations in equipment (*e.g.* mobile phones), network coverage, and community literacy hamper the implementation of such surveillance systems in remote communities (11,20,21).

In Chad, the first study to precisely evaluate the health of pastoralists and their animals through a community-based One Health approach was conducted by Schelling and colleagues in 1999-2000 through interviews and clinical and laboratory investigations (22). They showed that the nomadic lifestyle and seasonal cycle affect both human and animal morbidity (17,22) and that the proximity to animals is a significant risk factor for contracting zoonoses (23–25). Since 2007, projects to improve the health of pastoralists have been implemented in some districts of Chad, with joint support from the Swiss Agency for Development and Cooperation (SDC) and the Chadian authorities (26–28). Deriving from such research projects and programs, One Health interventions for animal and human populations, such as joint vaccination campaigns, have proven effective in improving the health and economic situation of communities (28–30). However, One Health surveillance programs in agro-pastoral communities in Sub-Saharan African countries are still poorly developed (16).

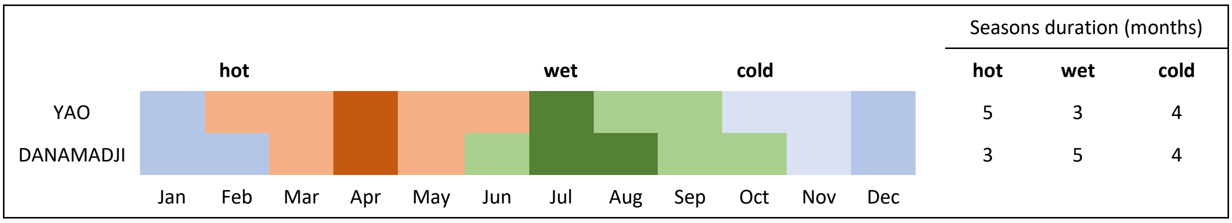
This study is part of a larger project investigating the feasibility of implementing a community-based syndromic surveillance system integrating a One Health approach in rural Chad. In the present study, we describe health information on human and animal populations, reported by communities of two rural health districts in Chad, Yao and Danamadji, in early 2018. Structured individual interviews were conducted with community members on the demographics of the surveyed households and the symptoms observed in humans and animals during the three main seasons of the past year. In the context of our study, we use the term 'community-based reporting of symptoms in a One Health approach' to describe the reporting by members of the communities surveyed of the presence of clinical signs of disease in both humans and animals. The results of this study will serve as a step towards implementing a real-time community-based syndromic surveillance system integrating a One Health approach.

2. Material and Methods

2.1. Study design and context

This cross-sectional study retrospectively compiled data on human and animal health from 2017, collected in January and February 2018 as a field survey. The study was conducted in Yao and Danamadji, the intervention regions of a SDC supported project called PADS (*Programme d'appui aux districts sanitaires au Tchad*), mainly focusing on maternal and infant health care (26,27,31). The field survey co-occurred with a seroprevalence study on brucellosis, Q-fever and Rift Valley fever (RVF) among humans and animals within the same communities (32). The health districts of Yao and Danamadji were selected as study regions because of the existing synergies between our project and the PADS, as well as the infrastructure and resources allowing this research campaign (maps, routes, accommodation, sample transport and storage facilities, community knowledge) (32). Each district has primary health centers and a secondary referral hospital (31). In 2017, the population of the two sanitary districts of Batha and Moyen-Chari was estimated to be 107'159 in Yao and 183'530 inhabitants in Danamadji (17). Most of the population has an agro-pastoral activity. Chad has several climatic and agro-ecologic areas with their respective vegetation, production systems, and socio-demographic realities (33), classified based on the latitude of isohyets, invisible lines of equal annual amounts of precipitation (34). Yao is situated in the Sahelian band around the isohyet 500 and Danamadji further south in the Sudanese zone around the isohyet 1100. In both regions, seasons follow a unimodal regimen of rainfall, with one rainy season and a marked dry period. In the communities interviewed, the dry season is usually divided into hot and cold seasons, with average maximum temperatures of 30 and 25°C, respectively. There is a high interannual variability of the season characteristics and duration (35,36). The duration of seasons in 2017 was determined for Yao and Danamadji based on the typical climate of these regions (35–38), the Agro-Pastoral Campaign Monitoring Bulletin in West Africa dated August 2017 (39) and exchange with our local collaborators (Figure 1).

Figure 1. Estimated duration of the main seasons in 2017 in Yao and Danamadji



2.2. Ethics

The overall project, of which this study was a part, has been approved by the Ethics Committee of Northwest and Central Switzerland (project id 2017-00884) and by the Comité National de Bioéthique du Tchad (project id 134/PR/MESRS/CNBT/2018), in accordance with the Declaration of Helsinki. Informed consent for further use of the survey data from humans and animals was obtained collegially within the villages or camps of the participants. Data are collected anonymously, with no possibility of linking the data to an identifiable person.

2.3. Study population

The sample size was calculated to serve the purpose of the seroprevalence study (32). Twenty-four clusters (12 camps and 12 villages) in each region, and 20 humans and 20 livestock animals within each cluster were to be sampled. The sampling followed a random two-stage cluster design. Camps (i.e., mobile settlements of communities) and villages (i.e., homes to sedentary communities) were selected in the first stage proportional to their human population size, and households in the second stage. A household was defined as people sharing a kitchen ((40)). The initially planned sampling strategy could not always be followed because camps moved according to seasons and pasture availability and sometimes could not be located, villages were abandoned, and consent to participate was denied in one case. We then included alternative households to which we had logistical access on the same day. This resulted in sampling one to several households per cluster and more clusters than initially planned. Each data point represents an interview with one household.

2.4. Data collection

The survey included structured interviews about symptoms observed by the community in humans and livestock. The survey was based on a questionnaire with implicit closed-ended questions written in English (**Error! Reference source not found.**), later translated into French and implemented in KoboCollect Toolbox, a cloud-based open-source software for field survey and data collection (www.kobotoolbox.org). A team of researchers from Institut de Recherche en Élevage pour le Développement au Chad experienced in collecting data in similar research contexts, carried out the field interviews. They were accompanied by veterinarians from the Veterinary Public Health Institute of Bern. The data collection team attended a training session on the study protocol and ethical considerations prior to field deployment. Upon arrival at the selected village or camp, the team first spoke with the community leader. Then, usually, a community gathering took place. The purpose of the study, as well as later the interviews, was explained verbally in Arabic or the local language. In most cases, the consent of community members to participate in the study was delegated to the community chief and, in some places, to the assembly of elders. Each participant was asked again individually if they wished to take part in the study at the time of the interviews. Participants were informed that they could withdraw from the entire study at any time or choose not to answer specific questions. We included questions on household demographics (number of people by age class, number of animals per species) and symptom occurrence in humans (number of cases per household) and animals (number of cases per species per household) each during the hot, wet, and cold seasons of the previous year. The symptoms interrogated were cough, diarrhea, cutaneous lesions, fever, weight loss, weakness, vertigo, and pale mucosa in humans and cough, diarrhea, cutaneous lesions, weight loss, weakness, mouth ulcer, hygroma, and altered behavior in animals (Table 1). Between the first (Danamadji) and the second (Yao) visited region, to avoid repetition for ethical and psychological concerns, we changed the way questions were stated around reproduction and mortality from seasonal to yearly observation. Unfortunately, this resulted in the loss of data for Danamadji. Therefore, the events of abortion, birth difficulty, birth, and death in humans and abortion and death in animals were available from Yao only and were not stratified by season (Table 1).

Table 1. Occurrence of symptoms surveyed during the study. In blue: symptoms reported in both humans and animals. • Symptoms reported in humans or animals that may be the manifestation of zoonosis, like brucellosis, Q-fever, and Rift Valley fever.

Reported Period	Region	Symptoms Human	Animal
3 seasons	Yao & Danamadji Danamadji	cough	cough
		diarrhea	diarrhea
		cutaneous lesion	cutaneous lesion
		fever •	
		weight loss	weight loss
		weakness	weakness
		vertigo	
		pale mucosa	
			mouth ulcer
			hygroma •
			altered behavior
Year	Yao	abortion	abortion •
		birth difficulty	
		birth	
		death	death

2.5. Data analysis

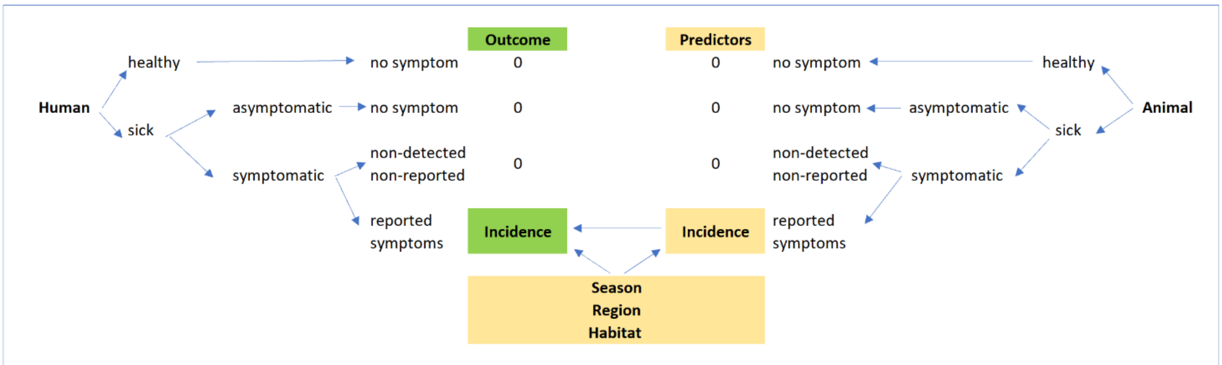
Data from KoboCollect were extracted and imported to R programming software for cleaning and analysis (R-project.org). Because of their rare occurrence within the surveyed communities, we excluded animal species other than bovine, goats, sheep, and camels from the analyses. These four are the main livestock species raised in the country (41). Since all these species are hosts for the zoonoses of interest (brucellosis, Q-fever or RVF), we combined the total number of cases (i.e., positive reported symptoms) for all species and analyzed them under the term "animals". Among symptoms listed in the survey, we analyzed those recorded simultaneously for humans and animals over the three seasons and in the two regions, *i.e.* cough, diarrhea, cutaneous lesions, weight loss and weakness (Table 1). We also looked at abortions and deaths for the entire year in Yao. Finally, we analyzed human fever associated with animal hygroma as typical symptoms of brucellosis and human fever associated with animal abortion, potentially caused by brucellosis, Q-fever or RVF. The incidence rate referred to in this article is the monthly incidence rate at the household level, calculated as the number of symptoms reported per household and per season, divided by the household population (human or animal) normalized per 1000 individuals, over the time of the respective seasons.

The incidence rate was stratified by symptom, season (cold, wet, hot), region (Yao, Danamadji), and habitat (village, camp). Characteristics of the study population and symptom incidence rates were summarised using descriptive statistics, *i.e.* medians and interquartile ranges for non-normally distributed and discrete variables. Univariable analysis for comparing the incidence rates between the categorical factors (season, habitat and region) was performed for each symptom in humans and animals, using the Kruskal-Wallis rank test. For seasons (three levels), Dunn's post hoc test and p-value Bonferroni adjustment were used.

The relationship between human and animal incidence rates per symptom was explored graphically via scatter plots and statistically by regression model, with the human incidence rate set as the outcome variable and the animal incidence rate, season, region, and habitat as predictors (Figure 2). We applied the model only to symptoms for which more than 10% of the households reported cases simultaneously in humans and animals, *i.e.*, cough, diarrhea, human fever versus animal hygroma, and human fever versus animal abortion. Due to the overdispersal distribution of the symptom incidence rates with an excess of zeros (**Error! Reference source not found.**), we chose a Zero-Inflated Negative Binomial Mixed Effects Model (42–45) to investigate associations between our outcome and predictors. The dataset was structured to include three observations per household for each symptom, one per season, and therefore, the household was defined as a random effect in the statistical model. For the categorical predictors season, region and habitat, the reference levels were cold season, Danamadji and camp, respectively. We included an interaction term between region and season in the model because of the bio-climatic context of the sampled areas. The Akaike Information Criteria (AIC) was used to select the model that best fitted our data (46).

Figure 2. Prediction model for reported symptom incidence rate. For each symptom, a zero-inflated negative binomial regression model was used to assess the influence of animal incidence rate, season, region, and habitat

on the human incidence rate.



3. Results

3.1. Study population

A total of 92 households were surveyed in 63 clusters (Table 2). Of the 92 surveys, 54 occurred in Danamadji, 38 in Yao, 51 in camps and 41 in villages (Table 3). The study population comprised 1373 people, with the median number of people per household and the age distribution comparable between the two regions and the two types of habitats (Table 3). All households kept animals, which summed up to 8291 animals. The median number of animals per household was similar between Yao and Danamadji (Table 3). The median number of animals per household and the animal-to-human ratio were higher in camps than in villages. The distribution of animal species was similar in camps and villages but heterogeneous between regions. Cattle were more common in Danamadji than in Yao, while goats were less common in Danamadji than in Yao. The proportion of sheep out of all species was similar between the two regions. The camels represented less than 1% of the total animal population and were only found in Yao and the camps.

Table 2. Structure of households and clusters sampled.

Number of households / cluster	Number of clusters
1	39
2	21
3	2
5	1

Table 3. Characteristics of human and animal populations reported during interviews.

		Region		Habitat	
	Total	Danamadji	Yao	Camp	Village
Household n	92	54	38	51	41
People n	1373	721	652	696	677
Median (IQR) / household	13 (10-18)	12 (9-16)	14 (10-20)	13 (9-16)	14 (10-18)
Age distribution					
≤5	268 (20%)	131 (18%)	137 (21%)	149 (22%)	119 (18%)
6 to 15	469 (35%)	252 (36%)	217 (34%)	257 (37%)	212 (32%)
16 to 25	292 (22%)	158 (22%)	134 (21%)	143 (21%)	149 (22%)
≥26	325 (24%)	168 (24%)	157 (24%)	138 (20%)	187 (28%)
unknown	19 (1%)	12 (2%)	7 (1%)	9 (1%)	10 (1%)
Animal n	8291	4702	3589	5812	2479
Median (IQR) / household	61 (26-128)	61 (27-127)	60 (24-148)	90 (48-163)	35 (18-70)
Animal/people ratio	6.0	6.5	5.5	8.4	3.7
Species distribution					
Cattle	4273 (52%)	2935 (62%)	1338 (37%)	2912 (50%)	1361 (55%)
Goats	1415 (17%)	371 (8%)	1044 (29%)	956 (16%)	459 (19%)
Sheep	2578 (31%)	1396 (30%)	1182 (33%)	1919 (33%)	659 (27%)
Camels	25 (0.3%)	0 (0%)	25 (0.7%)	25 (0.4%)	0 (0%)

3.2. Reported symptoms

In humans, fever was the symptom reported with the highest incidence rate (43.7 / 1000 people per month at the sample population level). Of the symptoms recorded in humans and animals, the most frequent, in descending order, were cough, diarrhea and cutaneous problems, followed by weakness and weight loss in humans, and weight loss and weakness in animals. Significant differences between seasons, regions or habitats were found for some symptoms (Table 4).

Table 4. Incidence rates of symptoms reported in humans and animals, in total and stratified per season, region and habitat type. Abortion and mortality were reported only for the whole year and in Yao. [a] rate/1000 individuals.month in the study population. [b] rate/1000 individuals.month at the level of households. [c] rate/1000 individuals.year in the total study population. [d] rate/1000 individuals.year at the level of households. † 25-75 percentile (at the household level, for clarity reasons, the 25th percentile is presented only when it is non-zero).

				Season			Region		Habitat	
Incidence			total	hot	wet	cold	Danamadji	Yao	camp	village
Cough										
	Human	rate [a]	22.5	5.4	4.7	12.4	24.7	20.1	23.5	21.5
		median (75th percentile) [b]	0.0 (50.0)	0.0 (42.8)	0.0 (28.0)	36.6 (62.5)	0.0 (50.0)	14.0 (37.6)	0.0 (50.0)	16.0 (40.4)
	Animal	rate [a]	19.0	3.6	6.2	9.3	18.9	19.1	19.2	18.6
		median (75th percentile) [b]	0.0 (35.1)	0.0 (20.6)	0.0 (28.3)	18.9 (48.7)	0.0 (37.6)	0.0 (28.0)	0.0 (35.7)	0.0 (33.3)
Diarrhea										
	Human	rate [a]	15.7	5.3	6.7	3.6	16.2	15.2	18.4	12.9
		median (75th percentile) [b]	0.0 (31.3)	0.0 (37.6)	0.0 (39.4)	0.0 (17.3)	0.0 (33.3)	0.0 (29.9)	0.0 (38.8)	0.0 (25.0)
	Animal	rate [a]	13.4	3.2	6.3	3.9	11.0	16.6	13.4	13.3
		median (75th percentile) [b]	0.0 (14.3)	0.0 (12.2)	0.0 (39.4)	0.0 (9.0)	0.0 (7.5)	0.0 (31.3)	0.0 (15.3)	0.0 (12.5)

Cutaneous lesions									
	Human	rate [a]	8.5	1.8	6.0	1.0	6.1	11.1	10.1	6.9
		median (75th percentile) [b]	0.0 (0.0)	0.0 (0.0)	0.0 (39.8)	0.0 (0.0)	0.0 (0.0)	0.0 (25.8)	0.0 (0.0)	0.0 (0.0)
	Animal	rate [a]	9.5	1.6	5.0	2.9	5.8	14.3	10.3	7.7
		median (75th percentile) [b]	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (2.3)	0.0 (0.0)	0.0 (0.0)	0.0 (5.7)	0.0 (0.0)
Weight loss									
	Human	rate [a]	1.9	1.0	0.7	0.4	1.5	2.3	0.5	3.3
		median (75th percentile) [b]	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Animal	rate [a]	6.9	5.3	0.4	1.2	4.7	9.8	6.2	8.8
		median (75th percentile) [b]	0.0 (19.6)	0.0 (22.7)	0.0 (55.2)	0.0 (0.0)	0.0 (8.0)	0.0 (40.6)	0.0 (18.2)	0.0 (22.2)
Weakness									
	Human	rate [a]	4.4	1.3	1.8	1.3	5.7	2.9	3.8	4.9
		median (75th percentile) [b]	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Animal	rate [a]	3.5	3.1	0.1	0.3	2.6	4.7	2.9	4.8
		median (75th percentile) [b]	0.0 (5.5)	0.0 (12.4)	0.0 (18.3)	0.0 (0.0)	0.0 (4.2)	0.0 (12.6)	0.0 (4.2)	0.0 (11.5)
Fever									
	Human	rate [a]	43.7	10.7	24.9	8.1	55.8	30.3	56.0	31.0
		median (75th percentile) [b]	35.4 (100.0)	4.0 (68.9)	83.3 (30.5 - 111.9) †	0.0 (50.0)	50.0 (111.1)	17.7 (72.2)	50.0 (111.1)	18.5 (71.9)
Hygroma									
	Animal	rate [a]	7.3	1.6	1.9	3.7	6.8	7.9	6.9	8.0
		median (75th percentile) [b]	0.0 (6.2)	0.0 (0.0)	0.0 (0.0)	0.0 (14.3)	0.0 (7.1)	0.0 (5.0)	0.0 (7.4)	0.0 (0.0)
Abortion									
	Human	rate [c]	6.6						10.1	3.0
		median (75th percentile) [d]	0.0 (0.0)						0.0 (40.0)	0.0 (0.0)
	Animal	rate [c]	70.3						76.0	56.9
		median (75th percentile) [d]	115.5 (140.3)						142.9 (115.3)	100.0 (160.2)
Mortality									
	Human	rate [c]	1.5						1.4	1.5
		median (75th percentile) [d]	0.0 (0.0)						0.0 (0.0)	0.0 (0.0)
	Animal	rate [c]	146.5						156.1	124.2
		median (75th percentile) [d]	197.3 (202.6)						206.2 (254.7)	197.3 (157.8)

3.3. Predicting incidence rates of symptoms in human

3.3.1. Diarrhea and cough

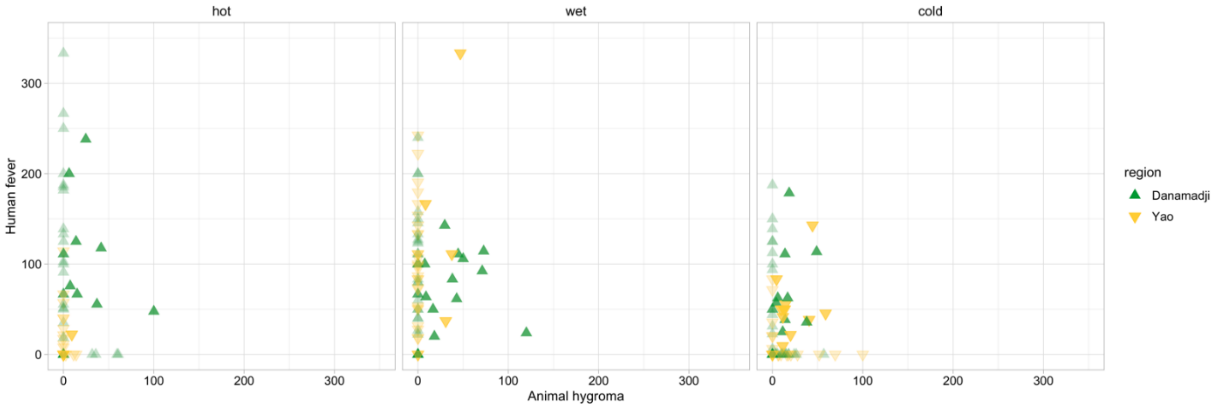
The relation between the incidence rate of human and animal symptoms is illustrated in Figure 3 for cough and diarrhea and in **Error! Reference source not found.** for cutaneous lesions, weight loss and weakness. Results from the best-fitting regression model aiming to predict the incidence rate of human symptoms are shown in Table 5. The incidence rates of cough and diarrhea in animals were not significantly associated with the incidence rate of these symptoms in humans. The region significantly affected the incidence rate of cough and diarrhea in humans. Living in Yao proved to be a protective factor for both symptoms compared with Danamadji. The seasons also had significant effects. The hot season was a risk factor for the cough and diarrhea incidence rate compared to the cold season. On the contrary, the wet season was identified as a protective factor for cough compared to the cold season. A significant interaction effect was found between seasons and regions. In Yao, the wet season had a more substantial effect on cough and diarrhea than in Danamadji. The hot season had less impact on cough in Yao.

Table 5. Results from the count part of the multivariable zero-inflated negative binomial regression model with mixed effects design to investigate the association between the monthly incidence rates at the household level of human symptoms (cough, diarrhea, fever) versus animal symptoms (cough, diarrhea and hygroma, respectively), season and region. Results for human fever yearly incidence rate at the household level versus animal abortion incidence rate and habitat are also presented. Category references: region Danamadji, season cold, habitat camp. x denotes the interaction effect between region and season. Bold estimates characterize the statistically significant variables.

Symptom	Predictor	Category	β	95% IC			p-value	
Cough	(Intercept)		4.07	3.85	,	4.28	<0.001	
	animal		0.00	0.00	,	0.00	0.17	
	region	Yao	**-0.34**	-0.63	,	-0.06	0.02	*
	season	wet	**-0.46**	-0.69	,	-0.22	<0.001	***
		hot	**0.26**	0.09	,	0.44	0.004	**
	region x season	Yao x wet	**0.43**	0.12	,	0.74	0.01	**
		Yao x hot	**-0.69**	-1.01	,	-0.38	<0.001	***
Diarrhea	(Intercept)		3.87	3.58	,	4.17	<0.001	
	animal		0.00	0.00	,	0.00	0.97	
	region	Yao	**-0.70**	-1.08	,	-0.33	<0.001	***
	season	wet	-0.03	-0.33	,	0.27	0.86	
		hot	**0.32**	0.05	,	0.59	0.02	**
	region x season	Yao x wet	**0.66**	0.26	,	1.06	0.001	**
		Yao x hot	0.01	-0.42	,	0.44	0.96	
Fever in human	(Intercept)		4.23	4.00	,	4.47	<0.001	
	animal hygroma		0.00	0.00	,	0.01	0.80	
	region	Yao	**-0.51**	-0.87	,	-0.15	0.006	**
	season	wet	**0.27**	0.05	,	0.49	0.02	*
		hot	**0.46**	0.25	,	0.68	<0.001	***
	region x season	Yao x wet	**0.60**	0.25	,	0.95	<0.001	***
		Yao x hot	**-0.66**	-1.08	,	-0.25	0.002	**
Fever in human	(Intercept)		6.57	6.07	,	7.08	<0.001	
	animal abortion		0.00	0.00	,	0.00	0.49	
	habitat	village	**-0.58**	-1.03	,	-0.13	0.012	*

Figure 3. Relation between the incidence rate of human and animal symptoms reported at the household level (rate/1000 individuals.month) for the hot, wet and cold seasons, and the two regions Yao and Danamadji: cough and diarrhea.

Figure 4. Relation between the incidence rate of fever in humans and hygroma in animals reported at the household level (rate/1000 individuals.month) for the three seasons hot, wet and cold, and the two regions Yao and Danamadji.



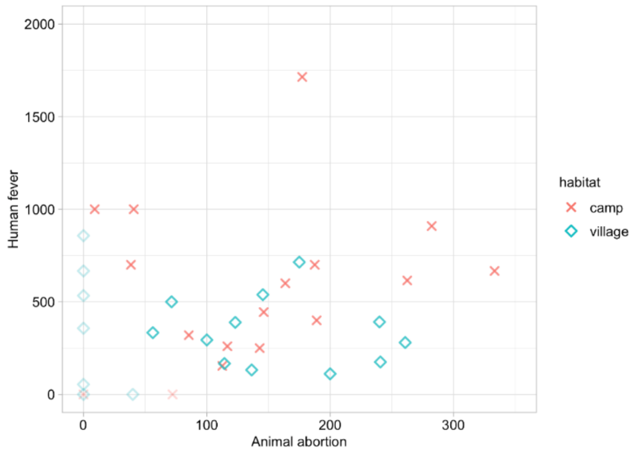
3.3.2. Human fever versus animal hygroma

Modelling of the association between human fever and animal hygroma showed no significant effect between the two symptoms (Figure 4 and Table 5). The incidence rate of fever was significantly increased during the wet and hot seasons compared to the cold season and significantly lower when living in Yao instead of Danamadji. When residing in Yao, the adverse effect of the wet season was significantly increased, but that of the hot season was significantly attenuated.

3.3.3. Human fever versus animal abortion

In Yao, the incidence rate of abortion in animals is not significantly associated with the incidence rate of fever in people (Figure 5 and Table 5). The regression model showed a significant protective effect of living in villages rather than in camps on the fever incidence rate in Yao.

Figure 5. Relation between the incidence rate of fever in humans and abortion in animals reported at the household level in Yao for the whole study year (rate/1000 individuals.year).



4. Discussion

4.1. Study aims and concepts

In this study, we assessed the co-occurrence of symptoms in agro-pastoralists and their animals, reported by the community members. Our study was cross-sectional and retrospective, based on people's recollections of symptoms appearing during the past year. It demonstrated that community members in remote regions can relate and record clinical signs in humans and livestock, potentially further used as data to infer health events by capturing unusual trends. It highlighted the potential capacity of community members as active contributors to surveillance systems in rural Chad. This work contributes, together with the results of a serological study conducted simultaneously in the same sample population (32), to implement a One Health community-based syndromic surveillance in agro-pastoral populations in Chad (17).

The study followed a One Health approach by including simultaneous recordings of symptoms in humans and animals and assessing the relationship of their respective incidence rates. Environmental aspects (habitat, season and region), often overlooked in One Health studies (47), were also recorded during the survey and included in the data analysis. By adding an interaction term to our regression model, we considered the intimate intertwining of the environmental factors, season and region, linked to the latitudinal climatic and agroecological contexts of the study areas. Moreover, where appropriate, the socio-environmental aspect underlaid in the type of habitat (sedentary village or nomadic camp) was considered in the analysis. Finally, the study adopted a transdisciplinary approach, important in the co-production of knowledge in One Health studies (48–51), by integrating different stakeholders, representing the targeted at-risk population, local authorities, and the research team. The agro-pastoral communities were both beneficiaries and actors of the project, as their willingness to participate and their traditional knowledge of the health of their livestock were considered.

4.2. Animal and human study populations

Our results showed a heterogeneous species distribution between the two study regions, corresponding to their respective agroecological profiles. Cattle were found to be more abundant in the Sudanese region of Danamadji, whose grasslands suited their needs, while goats make better use of the dry resources of the Sahelian band in Yao. Camels are particularly well adapted to the Sahelian climate. In our study, camels were consistently only found in Yao. Although we did not interrogate this aspect, ethnicity is also a factor explaining species distribution. In Yao, most sedentary people belong to the Bilala, while Arabs are mainly mobile pastoralists (17). The Arabs are usually camel and cattle herders (52). In Danamadji, the sedentary people are mainly from the Sara ethnic group, while the pastoralists are dominated by the Arabs, followed by the Fulani (17). The Fulani are traditional cattle herders (53).

4.3. Reported symptoms

Fever was the symptom with the highest incidence rate in humans, followed by cough, diarrhea and skin lesions. These findings are consistent with the leading causes of medical consultations in Chad, which are, in order of importance, malaria, respiratory problems, diarrheal diseases and skin infections (traumas and child malnutrition complete the picture, especially in the Sahel) (54). On the animal side, the most reported symptoms were cough, diarrhea and skin lesions. The limited data available from the REPIMAT (Réseau d'épidémiosurveillance des maladies animales au Tchad) annual report showed that pasteurellosis, anthrax, foot and mouth disease, peste des petits ruminants, and contagious pleuropneumonia bovine and caprine were among the most reported diseases based on clinical suspicion in the field (from our local collaborators), which could be consistent with the symptomatology reported in our survey. However, the reporting of cases within the framework of the REPIMAT is limited to clinical suspicions without laboratory diagnostic confirmation (55).

We investigated whether the incidence rate of specific symptoms in humans was related to the same symptoms in animals, adjusted for different environmental factors (season, region, habitat). A significant association can be expected if both the human and animal populations suffered from the same type of diseases under the same conditions (*e.g.* respiratory infections during the dry season) or from zoonotic diseases with similar clinical presentation in humans and animals (*e.g.* cryptosporidiosis, dermatophytosis or acariasis). However, some zoonoses have a different clinical presentation in animals and humans, such as abortion in animals and flu-like syndrome in humans for brucellosis, Q-fever or RVF. Therefore, we also compared species-specific symptoms for these three priority zoonoses in the region. These analyses revealed no statistical association between the incidence rate of symptoms in animals and humans for the observed period. The fact that we collected data retrospectively and only on a particular spectrum of symptoms could be an explanation. To go further, we examined the epidemiological context of the study year. For 2017, the WOAH-WAHIS portal indicated no reported Q-fever, RVF and *Brucella ovis* cases. Cases of *B. melitensis* were only notified from January to June and were not registered for the rest of the year. No information was available for *B. abortus*. This aligns with the 2017 Agro-Pastoral Campaign Monitoring Bulletin of West Africa that reported no abnormal epizootic event in the region (39). In the serological study conducted in parallel with this work, the overall seroprevalence for brucellosis, Q-fever and RVF for both areas combined was estimated respectively at 0.5%, 11.0% and 9.5% in animals and 0.1%, 49.2% and 28.4% in humans (32). We cannot infer the presence of infectious outbreaks from serological studies. That being said, except for brucellosis, whose seroprevalence is very low in humans and animals, the other serological results do not indicate similar exposure to Q-fever and RVF in humans and animals.

4.4. Environmental factors influencing the incidence rate of symptoms

4.4.1. Season

Cough occurred more frequently during the cold season in humans and animals. In addition, the regression model identified the hot season as a risk factor for developing cough in humans, consistent with other studies in the Sila region of Chad (38). The wet season was analyzed as a protective factor for cough in humans. Indeed, the cold and hot seasons are dry, with a high dust load, a factor of irritation and inflammation of the airways, increasing the risk of respiratory diseases (38,56). We observed a higher, although not significant, incidence rate of diarrhea during the wet season in both humans and animals, as observed in another study in Chad (22). The regression model identified the hot season as a risk factor for households with diarrhea cases. Indeed, the transition period between the hot and wet seasons can be considered a high-risk time for developing diarrheal diseases. At the end of the hot season, the first rains leach the soils, and the joint use of water points by humans and animals often leads to the contamination of surface water by coliforms and cryptosporidia, causing diarrhea (38,57). Animal weight loss and weakness occurred more during the hot and wet seasons. During this transition period, livestock is actually known to be exhausted and starved by the dry season (38). For pastoralists, Nathan *et al.* observed that malnutrition peaks at the end of the hot and the beginning of the wet seasons, critical periods of low production (58). However, in pastoralists, weight loss was rarely reported, possibly due to the biases described in the limitations section below. We observed a higher incidence rate of fever in humans during the wet season, corresponding to the typical peak of vector-borne diseases, such as malaria (38). Milk production is also high during the rainy season, especially in cows. This is associated with a risk of food-borne infections from consuming raw milk (7,38). We found that cutaneous lesions were more common during the wet season in humans and animals, which can encompass various pathological conditions. Little literature on Chadian veterinary and human dermatology makes interpreting the etiology of the observed symptoms challenging. One cause may be related to the biology of endemic vector-borne cutaneous diseases, such as leishmaniasis (59–63).

4.4.2. Region

We also noted an interesting influence of the geographic location on symptom incidence rate, with a higher incidence rate of cutaneous lesions and weight loss reported in Yao and more fever cases reported in Danamadji. The sub-Saharan environment of Yao may favor malnutrition and weight loss, while the more humid climate of Danamadji may favor vector-borne diseases leading to fever, such as malaria. However, the higher incidence rate of cutaneous lesions in Yao is difficult to interpret; further investigations would be needed to explain these observations. Likewise, in humans, there was a higher cough and diarrhea incidence rate in Danamadji than in Yao. Rather than the geography, we think that the respective climatic conditions of the regions caused this finding. The significant interaction terms between region and season in the regression models highlighted that the influence of the wet season on cough and diarrhea incidence rate was more marked in Yao than in Danamadji. In contrast, the effect of the hot season on the same symptoms was higher in Danamadji. This can be explained by the fact that rain has a more substantial influence in the hotter and drier climate of Yao than in the more humid conditions of Danamadji, referring to the so-called concentration-dilution hypothesis (64). The latter suggests that pathogens concentrate in limited water points during the dry period and then are washed away by heavy rains, notably contaminating groundwater. The climate-disease relationship at play in the more important effect of the hot season in Danamadji and its humid climate than in Yao is harder to interpret. Water, Sanitation and Hygiene should be taken into account (57).

4.4.3. Habitat

Living in a village was analyzed in our model as a protective factor for the occurrence of fever in humans. When considering malaria as the primary cause of fever, we may hypothesize that the protection against mosquitoes is less prevalent in camps than in villages. However, this needs to be confirmed by the literature. Bechir *et al.* found no difference in the prevalence of parasitic infection between the mobile pastoralists and rural sedentary populations in Chad (65). In Mali, the settled agricultural people suffered higher rates of parasitic infection and malaria than nomadic groups (66). Therefore, it is difficult to interpret our observation, especially in the absence of information on measures to prevent mosquito bites and the presence of standing water in the study environment (67). We also observed more reports of human abortions in camps than in villages. In Mali, Traore *et al.* observed more risky behavior of brucellosis transmission among pastoralists compared to people living in other husbandry systems (68). In Ethiopia, a higher brucellosis seroprevalence was observed in pastoral systems compared to settled and mixed farming systems (69). Transmissions of zoonotic diseases to humans that result in abortion might be more common in such settings due to the closer proximity to animals in camps or the lower protective measures in these communities. However, this hypothesis would require further investigation. Socioeconomic aspects should also be considered to explain higher abortion rates among mobile versus settled communities, such as less access to health care, particularly during pregnancy and around childbirth, due, among other things, to high mobility.

4.5. Limitations

The relatively long questionnaire, interview duration, and repetitive questions limited the attention of participants. The fact that the questionnaire was translated several times (from English to French to local languages and back to English for data analysis) may also introduce misunderstandings, not to mention the diversity of the semantic interpretation of some medical terms. A linguistic and cultural analysis of equivocal terms would have been useful upstream. The latter limitation may have led to bias in reporting symptoms, especially those with no apparent clinical manifestation, like weakness or weight loss. We found that these symptoms were reported less frequently than others in humans and animals. Weakness may be confused with other reported symptoms, such as vertigo in humans or altered behavior in animals, also queried in our questionnaire. Weight loss is a somewhat subjective symptom that is difficult to standardize without weighting individuals. This may have caused underreporting of these general symptoms, compared to cough or diarrhea. It was also challenging to collect information on abortion and death in humans and animals. Sociological and psychological biases may have affected the narrative of human deaths and reproductive events, leading to under-reporting. Yet, Chad has some of the highest maternal mortality rates (856/100'000 live births) and infant mortality under five (107/1'000 births) in the world (33,70). Faced with the difficulty for people to recount these events, we changed the questionnaire strategy during the study, preventing us from comparing these parameters between the two regions. Additionally, inherent to the retrospective aspect of our survey, recall bias cannot be avoided. This bias may be even more pronounced for symptoms that are difficult to recognize. A real-time reporting system would specifically prevent this issue.

5. Conclusion

Overall, our results showed that the incidence of reported symptoms in humans and animals was influenced by environmental factors, such as season, region, and habitat, as already known to impact the regional morbidity of the local human and animal populations. This consistency demonstrates the interest and relevance of our survey. We could not detect a statistical association between reported symptoms in humans and animals, likely since no major zoonotic events occurred during the study period. Yet we demonstrated that the spatial and time trends in symptom incidences were similar between human and animal populations. The study also showed that observing specific symptoms across communities, at least those with an apparent clinical manifestation, is possible. Building on these findings, real-time simultaneous reporting of human and animal symptoms could be used to improve surveillance systems in these remote regions with low healthcare coverage. Such a One Health integrated syndromic surveillance would be highly valuable for the health of agro-pastoral communities and their animals in Chad and potentially beyond.

Credit authorship contribution statement

Camille Doras analyzed the data and authored this manuscript. Ranya Özcelik collected the field data in Chad, conducted preliminary analyses and reviewed this manuscript. Camille Doras and Ranya Özcelik contributed equally to this article. Mahamat Fayiz Abakar supported the field investigation, advised on the local conditions of this work, and reviewed the manuscript. Ramadan Issa, Pidou Kimala and Soumaya Youssouf participated in the field sampling. Isabelle Bolon reviewed this manuscript and suggested additional analyses. Salome Dürr supervised and reviewed this work and manuscript.

Declaration of Competing Interest

No authors have competing interests.

Funding

This study was supported by the Wolfermann-Nägeli-Stiftung (grant no. 2016/19) and the Swiss Food Safety and Veterinary Office (grant no. 1.17.09).

Data availability

Data will be made available on request.

Acknowledgements

We acknowledge the pastoral communities for having consented and actively participating in this study in 2018.

References

1. WHO. Pandemic prevention, preparedness and response accord [Internet]. 2023 [cited 2023 Aug 31]. Available from: https://www.who.int/news-room/questions-and-answers/item/pandemic-prevention--preparedness-and-response-accord
2. Jones KE, Patel NG, Levy MA, Storeygard A, Balk D, Gittleman JL, et al. Global trends in emerging infectious diseases. Nature. 2008 Feb;451(7181):990–3.
3. Smith KF, Goldberg M, Rosenthal S, Carlson L, Chen J, Chen C, et al. Global rise in human infectious disease outbreaks. J R Soc Interface. 2014 Dec 6;11(101):20140950.
4. WHO. WHO | Regional Office for Africa. 2023 [cited 2023 Aug 31]. In Africa, 63% jump in diseases spread from animals to people seen in last decade. Available from: https://www.afro.who.int/news/africa-63-jump-diseases-spread-animals-people-seen-last-decade
5. Worsley-Tonks KEL, Bender JB, Deem SL, Ferguson AW, Fèvre EM, Martins DJ, et al. Strengthening global health security by improving disease surveillance in remote rural areas of low-income and middle-income countries. Lancet Glob Health. 2022 Apr 1;10(4):e579–84.
6. Hassell JM, Muloi DM, VanderWaal KL, Ward MJ, Bettridge J, Gitahi N, et al. Epidemiological connectivity between humans and animals across an urban landscape. Proc Natl Acad Sci. 2023 Jul 18;120(29):e2218860120.
7. Montavon A, Jean-Richard V, Bechir M, Daugla DM, Abdoulaye M, Bongo Naré RN, et al. Health of mobile pastoralists in the Sahel – assessment of 15 years of research and development. Trop Med Int Health. 2013;18(9):1044–52.
8. Henning KJ. What is Syndromic Surveillance? Morb Mortal Wkly Rep CDC. 2004 Sep 24;53 (Suppl.):5–11.
9. Kogan NE, Bolon I, Ray N, Alcoba G, Fernandez-Marquez JL, Müller MM, et al. Wet Markets and Food Safety: TripAdvisor for Improved Global Digital Surveillance. JMIR Public Health Surveill. 2019 Apr 1;5(2):e11477.
10. Heymann DL, Dixon M. The Value of the One Health Approach: Shifting from Emergency Response to Prevention of Zoonotic Disease Threats at Their Source. Microbiol Spectr. 2013 Oct;1(1).
11. Zinsstag J, Crump L, Schelling E, Hattendorf J, Maidane YO, Ali KO, et al. Climate change and One Health. FEMS Microbiol Lett. 2018 Apr 4;365(11):fny085.
12. Guerra J, Acharya P, Barnadas C. Community-based surveillance: A scoping review. PloS One. 2019;14(4):e0215278.
13. Technical Contributors To The June Who Meeting. A definition for community-based surveillance and a way forward: results of the WHO global technical meeting, France, 26 to 28 June 2018. Euro Surveill Eur Commun Dis Bull. 2019 Jan;24(2).
14. Ratnayake R, Tammaro M, Tiffany A, Kongelf A, Polonsky JA, McClelland A. People-centred surveillance: a narrative review of community-based surveillance among crisis-affected populations. Lancet Planet Health. 2020 Oct 7;4(10):e483–95.
15. Osman Y, Ali SM, Schelling E, Tschopp R, Hattendorf J, Muhumed A, et al. Integrated community based human and animal syndromic surveillance in Adadle district of the Somali region of Ethiopia. One Health. 2021 Dec 1;13:100334.
16. Abakar MF, Schelling E, Béchir M, Ngandolo BN, Pfister K, Alfaroukh IO, et al. Trends in health surveillance and joint service delivery for pastoralists in West and Central Africa. Rev Sci Tech OIE. 2016 Aug 1;35(2):683–91.
17. Abakar MF, Ouedraogo B, Dürr S, Issaka MY. Surveillance Syndromique Mobile intégrée '"One Health"' utilisant les téléphones mobiles au Tchad SySMob [Internet]. 2018 [cited 2021 Nov 5]. Available from: https://c6a2cda5-0166-433c-8483-52ee3e113e2f.filesusr.com/ugd/57b3b0_726795bb93ee44c3b92cfc68142131a3.pdf

18. Brinkel J, Krämer A, Krumkamp R, May J, Fobil J. Mobile Phone-Based mHealth Approaches for Public Health Surveillance in Sub-Saharan Africa: A Systematic Review. Int J Environ Res Public Health. 2014 Nov;11(11):11559–82.
19. Thumbi SM, Njenga MK, Otiang E, Otieno L, Munyua P, Eichler S, et al. Mobile phone-based surveillance for animal disease in rural communities: implications for detection of zoonoses spillover. Philos Trans R Soc B Biol Sci. 2019 Sep 30;374(1782):20190020.
20. Kim Y, Huang J, Emery S. Garbage in, Garbage Out: Data Collection, Quality Assessment and Reporting Standards for Social Media Data Use in Health Research, Infodemiology and Digital Disease Detection. J Med Internet Res. 2016 Feb 26;18(2):e41.
21. Zinsstag J, Schelling E, Crump L, Whittaker M, Tanner M, Stephen C. One Health, 2nd Edition: The Theory and Practice of Integrated Health Approaches. CABI; 2020. 459 p.
22. Schelling E. Human and Animal Health in Nomadic Pastoralist Communities of Chad: Zoonoses, Morbidity and Health Services. 2nd edition [2001] [Internet]. NCCR North-South Dialogue; 2007 [cited 2021 Nov 10]. Available from: https://www.nccr-north-south.unibe.ch/upload/Schelling_NCCR_Dialogue_1.pdf
23. Remadji H, Neneck AK, Colosio V, Ripoll S. L'Afrique contre les épidémies : Principales considérations en matière de préparation et de riposte aux épidémies au Tchad, Note d'information [Internet]. 2020 [cited 2021 Nov 8]. Available from: https://www.socialscienceinaction.org/wp-content/uploads/2021/09/TDDAP-Key-Considerations-Epidemic-Response-Preparedness-CHAD_FR.pdf
24. Greter H, Batil AA, Ngandolo BN, Alfaroukh IO, Moto DD, Hattendorf J, et al. Human and livestock trematode infections in a mobile pastoralist setting at Lake Chad: added value of a One Health approach beyond zoonotic diseases research. Trans R Soc Trop Med Hyg. 2017 Jun 1;111(6):278–84.
25. WHO. Communicable disease epidemiological profile - Central African Republic and Chad [Internet]. WHO/HSE/GAR/DCE/2009.2; 2009 [cited 2021 Nov 11]. Available from: https://www.who.int/diseasecontrol_emergencies/toolkits/chad_20091214_en.pdf
26. PADS. PADS Tchad. 2022 [cited 2022 Mar 10]. PADS Tchad. Available from: https://www.pads-tchad.org
27. Swiss TPH. Swiss TPH. 2022 [cited 2022 Mar 10]. Support Project for the Health Districts in Chad - Phase II. Available from: https://www.swisstph.ch/de/projects/project-detail/project-action/detail/project-controller/Projects/project/support-project-for-the-health-districts-in-chad-phase-ii/
28. Schelling E, Bechir M, Ahmed MA, Wyss K, Randolph TF, Zinsstag J. Human and animal vaccination delivery to remote nomadic families, Chad. Emerg Infect Dis. 2007 Mar;13(3):373–9.
29. Schelling E, Wyss K, Béchir M, Moto DD, Zinsstag J. Synergy between public health and veterinary services to deliver human and animal health interventions in rural low income settings. BMJ. 2005 Nov 26;331(7527):1264.
30. Zinsstag J, Schelling E, Roth F, Bonfoh B, de Savigny D, Tanner M. Human Benefits of Animal Interventions for Zoonosis Control. Emerg Infect Dis. 2007 Apr;13(4):527–31.
31. Lechthaler F, Abakar MF, Schelling E, Hattendorf J, Ouedraogo B, Moto DD, et al. Bottlenecks in the provision of antenatal care: rural settled and mobile pastoralist communities in Chad. Trop Med Int Health. 2018;23(9):1033–44.
32. Özcelik R, Abakar MF, Counotte MJ, Abdelrazak Zakaria F, Kimala P, Issa R, et al. Seroprevalence and associated risk factors of brucellosis, Rift Valley fever and Q fever among settled and mobile agro-pastoralist communities and their livestock in Chad. Marques ETA, editor. PLoS Negl Trop Dis. 2023 Jun 23;17(6):e0011395.
33. WHO. Stratégie de coopération, un aperçu - Tchad. [Internet]. WHO/CCU/18.02/Tchad; 2018 [cited 2021 Nov 11]. Available from: https://apps.who.int/iris/bitstream/handle/10665/137147/ccsbrief_tcd_fr.pdf;sequence=1
34. International Institute of Tropical Agriculture. IITA West Africa Trial site 2019. 2021 [cited 2022 Mar 10]. IITA West Africa Trial site 2019. Available from:

https://csi.maps.arcgis.com/apps/MapSeries/index.html?appid=7539d22ab46147ce9888589aea4b1a11
35. CEDEAO-CSAO/OCDE. Atlas de l'Intégration Régionale en Afrique de l'Ouest - Série environnement. La zone écologique fragile des pays du Sahel. 2016.
36. FAO. AQUASTAT Profil de Pays – Tchad. [Internet]. Rome, Italie: Organisation des Nations Unies pour l'alimentation et l'agriculture; 2005 [cited 2021 Nov 3] p. 15. Available from: https://www.fao.org/3/I9886FR/i9886fr.pdf
37. GIZ. Climate Risk Profile: Chad [Internet]. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH; 2021 [cited 2021 Nov 4]. Available from: https://agrica.de/wp-content/uploads/2021/01/GIZ_Climate-risk-profile-Chad_EN_final.pdf
38. Marshak A, Luc G, Radday A, Young H. De l'importance de la saisonnalité : comment les variations cycliques impactent la malnutrition aiguë dans la province du Sila au Tchad. Feinstein Int Cent. 2020 Nov;16.
39. Centre Régional AGRHYMET. Bulletin de suivi de la campagne agropastorale en Afrique de l'ouest - Bulletin mensuel n°08 - Août 2017 [Internet]. Comité permanent Inter-Etats de Lutte contre la Sècheresse dans le Sahel - CILSS; 2017 [cited 2021 Nov 4]. Available from: http://agrhymet.cilss.int/index.php/bulletins/
40. United Nations Department of Economic and Social Affairs/Population Division, editor. Principles and recommendations for population and housing censuses: 2020 round. Revision 3. New York: United Nations; 2017. 299 p. (Economic & social affairs).
41. FAO & CIRAD. Atlas of trends in pastoral systems in the Sahel 1970-2012 [Internet]. United Nations Food and Agriculture Organization of the United Nations (FAO) and Centre for International Cooperation in Agricultural Research for Development (CIRAD); 2012 [cited 2021 Nov 3]. Available from: https://www.fao.org/3/i2601e/i2601e.pdf
42. Rizopoulos D. GLMMadaptive. 2022 [cited 2022 Mar 31]. Zero-Inflated and Two-Part Mixed Effects Models. Available from: https://drizopoulos.github.io/GLMMadaptive/articles/ZeroInflated_and_TwoPart_Models.html#zero-inflated-negative-binomial-mixed-effects-model
43. Green JA. Too many zeros and/or highly skewed? A tutorial on modelling health behaviour as count data with Poisson and negative binomial regression. Health Psychol Behav Med. 2021 Jan 1;9(1):436–55.
44. UCLA - IDRE Stats. Statistical Consulting Web Resources. 2021 [cited 2021 Dec 7]. Zero-Inflated Negative Binomial Regression | R Data Analysis Examples. Available from: https://stats.idre.ucla.edu/r/dae/zinb/
45. Ver Hoef JM, Boveng PL. Quasi-poisson vs. Negative binomial regression: how should we model overdispersed count data? Ecology. 2007 Nov;88(11):2766–72.
46. Akaike H. Information Theory and an Extension of the Maximum Likelihood Principle. In: Parzen E, Tanabe K, Kitagawa G, editors. Selected Papers of Hirotugu Akaike [Internet]. New York, NY: Springer; 1998 [cited 2023 Aug 29]. p. 199–213. (Springer Series in Statistics). Available from: https://doi.org/10.1007/978-1-4612-1694-0_15
47. Essack SY. Environment: the neglected component of the One Health triad. Lancet Planet Health. 2018 Jun;2(6):e238–9.
48. Schelling E, Zinsstag J. Transdisciplinary research and One Health. One Health Theory Pract Integr Health Approaches. 2015 Jan;366–73.
49. Zinsstag J, Pelikan K, Gonzalez MB, Kaiser-Grolimund A, Crump L, Mauti S, et al. Value-added transdisciplinary One Health research and problem solving. In: Handbook of Transdisciplinarity: Global Perspectives [Internet]. Edward Elgar Publishing; 2023 [cited 2023 Sep 21]. p. 333–50. Available from: https://www.elgaronline.com/edcollchap/book/9781802207835/book-part-9781802207835-31.xml
50. OECD. Addressing societal challenges using transdisciplinary research [Internet]. Paris; 2020 Jun [cited 2023 Sep 21]. (OECD Science, Technology and Industry Policy Papers;

vol. 88). Report No.: 88. Available from: https://www.oecd-ilibrary.org/science-and-technology/addressing-societal-challenges-using-transdisciplinary-research_0ca0ca45-en
51. Berger-González M, Pelikan K, Zinsstag J, Ali SM, Schelling E. Transdisciplinary research and one health. One Health Theory Pract Integr Health Approaches. 2021 Jan;57–70.
52. Zakinet D. Transhumant Arab Tribes Move between Alliances and Conflicts in Central Chad. Afr Contemp. 2015;255(3):121–36.
53. Boutrais J. The Fulani and Cattle Breeds: Crossbreeding and Heritage Strategies. Africa. 2007 Feb;77(1):18–36.
54. Bechir M, Schelling E, Bonfoh B, Seydi M, Wade S, Moto DD, et al. [Seasonal variations in the nutritional status of nomad and sedentary children less than 5 years of age living in the Sahel in Chad]. Med Trop Rev Corps Sante Colon. 2010 Aug;70(4):353–8.
55. Mahamat O, Emiliana B, Santina G, Adel BY, Keith S, Pascal H, et al. Évaluation de la sensibilité du réseau d'épidémiosurveillance des maladies animales au tchad pour la surveillance de la fièvre aphteuse. 2017;
56. McElroy S, Dimitrova A, Evan A, Benmarhnia T. Saharan Dust and Childhood Respiratory Symptoms in Benin. Int J Environ Res Public Health. 2022 Apr 14;19(8):4743.
57. Dimitrova A, Gershunov A, Levy MC, Benmarhnia T. Uncovering social and environmental factors that increase the burden of climate-sensitive diarrheal infections on children. Proc Natl Acad Sci. 2023 Jan 17;120(3):e2119409120.
58. Nathan MA, Fratkin EM, Roth EA. Sedentism and child health among Rendille pastoralists of northern Kenya. Soc Sci Med 1982. 1996 Aug;43(4):503–15.
59. Toumi A, Chlif S, Bettaieb J, Ben Alaya N, Boukthir A, Ahmadi ZE, et al. Temporal dynamics and impact of climate factors on the incidence of zoonotic cutaneous leishmaniasis in central Tunisia. PLoS Negl Trop Dis. 2012;6(5):e1633.
60. Demba Kodindo I, Baïndaou G, Tchonfinet M, Ngamada F, Ndjékoundadé A, Moussa Djibrine M, et al. [Retrospective study of cutaneous leishmaniasis in the district hospital of Am Timan, Chad]. Bull Soc Pathol Exot 1990. 2015 Mar;108(2):117–9.
61. Amro A, Al-Dwibe H, Gashout A, Moskalenko O, Galafin M, Hamarsheh O, et al. Spatiotemporal and molecular epidemiology of cutaneous leishmaniasis in Libya. PLoS Negl Trop Dis. 2017 Sep;11(9):e0005873.
62. Sunyoto T, Verdonck K, el Safi S, Potet J, Picado A, Boelaert M. Uncharted territory of the epidemiological burden of cutaneous leishmaniasis in sub-Saharan Africa—A systematic review. PLoS Negl Trop Dis. 2018 Oct 25;12(10):e0006914.
63. Doss N, Kassir M. Role of national dermatology societies: A perspective from Tunis. Clin Dermatol. 2020 Oct;38(5):547–54.
64. Kraay ANM, Man O, Levy MC, Levy K, Ionides E, Eisenberg JNS. Understanding the Impact of Rainfall on Diarrhea: Testing the Concentration-Dilution Hypothesis Using a Systematic Review and Meta-Analysis. Environ Health Perspect. 128(12):126001.
65. Bechir M, Schelling E, Hamit MA, Tanner M, Zinsstag J. Parasitic Infections, Anemia and Malnutrition Among Rural Settled and Mobile Pastoralist Mothers and Their Children in Chad. EcoHealth. 2012 Jun;9(2):122–31.
66. Chabasse D, Roure C, ag Rhaly A, Ranque P, Quilici M. The health of nomads and semi-nomads of the Malian Gourma : an epidemiological approach. London, England, KPI; 1985.
67. Nabie Bayoh M, Akhwale W, Ombok M, Sang D, Engoki SC, Koros D, et al. Malaria in Kakuma refugee camp, Turkana, Kenya: facilitation of Anopheles arabiensis vector populations by installed water distribution and catchment systems. Malar J. 2011 Jun 4;10(1):149.
68. Traoré S, Yapi RB, Coulibaly K, Mathew C, Fokou G, Kazwala RR, et al. Seroprevalence of brucellosis in small ruminants and related risk behaviours among humans in different husbandry systems in Mali. PLoS ONE. 2021 Jan 22;16(1):e0245283.
69. Megersa B, Biffa D, Niguse F, Rufael T, Asmare K, Skjerve E. Cattle brucellosis in traditional livestock husbandry practice in Southern and Eastern Ethiopia, and its zoonotic implication. Acta Vet Scand. 2011 Apr 7;53(1):24.

70. World Bank. World Bank Open Data. 2023 [cited 2023 Aug 30]. World Bank Open Data. Available from: https://data.worldbank.org

Authors' statement

The authors state that the manuscript contains a statement that all procedures were performed in compliance with relevant laws and institutional guidelines and have been approved by the appropriate institutional committees. In addition, a statement is included in the manuscript that informed consent was obtained from participants. The privacy rights of human subjects must always be observed.

Text from the manuscript:

"The overall project, of which this study was a part, has been approved by the Ethics Committee of Northwest and Central Switzerland (project id 2017-00884) and by the Comité National de Bioéthique du Tchad (project id 134/PR/MESRS/CNBT/2018), in accordance with the Declaration of Helsinki. Informed consent for further use of the survey data from humans and animals was obtained collegially within the villages or camps of the participants. Data are collected anonymously, with no possibility of linking the data to an identifiable person."

Declaration of Competing Interest

None of the authors have competing interests.