

**One Health profile of a community at the wildlife-domestic animal interface,
Mpumalanga, South Africa**

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Highlights

- Developed profile of a rural community bordering wildlife using One Health approach
- Education on animal health was desired despite limited understanding of zoonoses
- Domiciliary rodent sightings associated with animal ownership and household size
- Frequency of consumption of animal source foods associated with animal ownership
- Favorable towards conservation but strong preference for separation from wildlife

Abstract

We used a community engagement approach to develop a One Health profile of an agro-pastoralist population at the interface of wildlife areas in eastern South Africa. Representatives from 262 randomly-selected households participated in an in-person, cross-sectional survey. Questions were designed to ascertain the participants' knowledge, attitudes, and practices with regard to human health, domestic animal health, and natural resources including wildlife and water. Surveys were conducted within four selected villages by a team of trained surveyors and translators over four weeks in July-August 2013. Questions were a combination of multiple choice (single answer), multiple selection, open-ended, and Likert scale.

The study found that nearly three-quarters of all households surveyed reported owning at least one animal (55% owned chickens, 31% dogs, 25% cattle, 16% goats, 9% cats, and 5% pigs). Among the animal-owning respondents, health concerns identified included dissatisfaction with government-run cattle dip facilities (97%) and frequent morbidity and mortality of chickens that had clinical signs consistent with Newcastle disease (49%). Sixty-one percent of participants believed that diseases of animals could be transmitted to humans. Ninety-six percent of respondents desired greater knowledge about animal diseases. With regard to human health issues, the primary barrier to health care access was related to transportation to/from the community health clinics. Environmental health issues revealed by the survey included

disparities by village in drinking water reliability and frequent domiciliary rodent sightings positively associated with increased household size and chicken ownership. Attitudes towards conservation were generally favorable; however, the community demonstrated a strong preference for a dichotomous approach to wildlife management, one that separated wildlife from humans.

Due to the location of the community, which neighbors the Great Limpopo Transfrontier Conservation Area, and the livestock-dependent lifestyle of the resource-poor inhabitants, a One Health approach that takes into consideration the interconnectedness of human, animal, and environmental health is necessary. The community profile described in this study provides a foundation for health research and planning initiatives that are driven by community engagement and consider the multitude of factors affecting health at the human-domestic animal-wildlife interface. Furthermore, it allows for the determination and quantification of the linkages between human, animal, and environmental health.

Abbreviations: MTA, Mnisi Traditional Authority; OH, One Health; TFCA, Transfrontier Conservation Area

Keywords: transfrontier conservation area, needs assessment, participatory epidemiology, community engagement, zoonoses, survey

Introduction

Africa has experienced dramatic shifts in human and animal population dynamics over the last century. Armed conflict, changes in land use, and a rapid rise in the human population have forced the movement of people and the re-establishment of communities in previously uninhabited areas (Kock *et al.*, 2002). In southern Africa, another such change in land use was the development of transfrontier conservation areas (TFCAs) in the early 2000s. There are currently 13 TFCAs under active development in Southern Africa. TFCAs have been promoted as a way to reconcile conservation and development objectives through increased cross-border collaboration and ecotourism (de Garine-Wichatitsky *et al.*, 2013). TFCAs seek to limit barriers between countries, thus allowing wildlife to roam more freely and promoting regional peace, cooperation, and socio-economic development (Department of Environmental Affairs, 2015). However, the increased movement of animals across the boundaries of these re-connected conservation areas presents new challenges for animal health and, in turn, adjacent human communities (Bengis, 2005). With the growing recognition of the interconnectivity of the health of all species with that of their environment, mitigation of disease transmission at the human-wildlife-livestock interface has become a major development and conservation objective (de Garine-Wichatitsky *et al.*, 2013).

The land of the Mnisi Traditional Authority (MTA) within the Bushbuckridge Local Municipality, Mpumalanga, South Africa exemplifies this interface. The Municipality contains over 500,000 people, and its entire eastern boundary borders the Great Limpopo TFCA. The Great Limpopo TFCA is one of the largest TFCAs in Southern Africa with a land area of nearly 100,000 km². It spans three countries (South Africa, Zimbabwe, and Mozambique) and contains five national parks. The people who reside in the Bushbuckridge Local Municipality on the

periphery of the Great Limpopo TFCA are characterized by a high degree of poverty and many rely on land-based activities such as agriculture and natural resource use for their livelihoods (Andersson *et al.*, 2013). In this area, the co-existence of humans, domestic animals, and wildlife is required and critical to the sustainability of the parks and success of wildlife conservation efforts.

Within the MTA, livestock dependence, coupled with proximity to wildlife areas, makes health promotion and poverty alleviation a more complex problem. A One Health (OH) approach that recognizes the interconnectedness of human, animal, and ecosystem health and encourages collaboration between diverse disciplines is ideally suited to address these types of problems (Mazet *et al.*, 2009; Conrad *et al.*, 2013; Grace, 2014). Integrated animal-human health surveillance using simultaneous data collection is a method by which to better understand these complex relationships (Thumbi *et al.*, 2015).

The goal of our study was to establish a baseline profile of a selected area within the MTA in order to plan follow-up research and activities that use a community-engaged, OH approach for the purposes of informing disease prevention and mitigation efforts in both human and animal populations. A community-engaged approach seeks participation from inhabitants and draws on the capacities and resources of those people, rather than a top-down approach. Community engagement is a core element of any research effort involving communities and may enhance a community's ability to identify and address its own health needs, disparities, and goals. In addition, results of community-engaged research are used to guide the development of interventions, education, or policies (Ahmed *et al.*, 2010).

This study seeks to describe human and animal demography within the study area and the perspectives of the people in terms of how they view their health; whether they acknowledge a

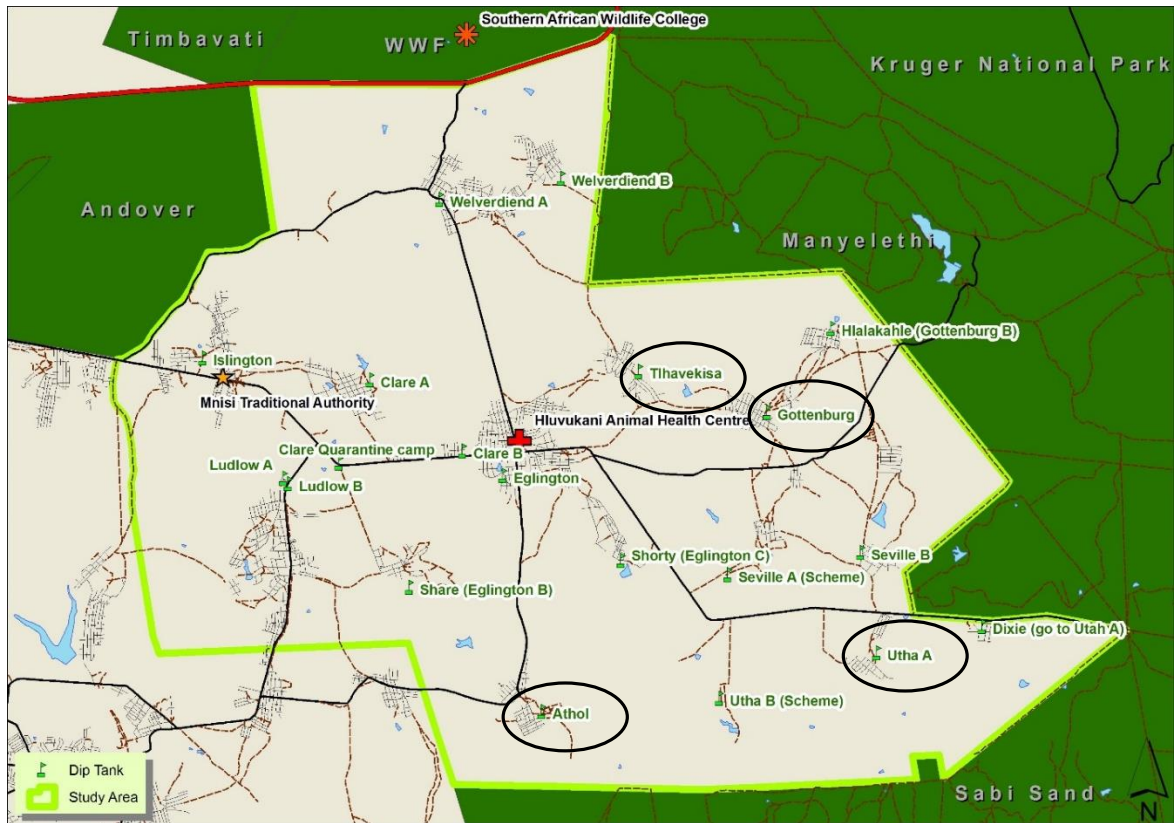
connection between their health, the health of their animals, and environmental factors; what they consider to be priority concerns for their community; how they perceive wildlife and conservation; their self-reported health history; and their satisfaction with health services. Triangulating knowledge, attitudes, and practices with self-reported health and disease history is an important step in community health research and planning that requires a community-engaged approach. Furthermore, quantifying linkages between livestock and human health remains a priority for developing sustainable poverty relief and public health interventions for livestock-dependent communities (Thumbi *et al.*, 2015). The result of this study will be a comprehensive OH profile of the study area. This profile can be used for subsequent health planning and research aimed at improving health and livelihoods of community members and mitigating disease risks.

Materials and methods

Study area

The study was carried out in a selected area within the MTA, hereafter referred to as the “Mnisi study area,” located in the Mpumalanga Province in the Republic of South Africa. The Mnisi study area is situated in the northeastern corner of the Bushbuckridge Local Municipality and is the core research and engagement area of the Mnisi Community Programme, Faculty of Veterinary Science, University of Pretoria (UP). The study area contains approximately 29,500ha of communal land, of which more than 75% borders private and provincial conservation areas (Figure 1). The study area includes the adjacent Andover and Manyeleti provincial game

Figure 1. Map of the Mnisi study area (outlined in light green), Mpumalanga Province, Republic of South Africa, highlighting the location of the four selected villages (circles). Image courtesy of Mnisi Community Programme, University of Pretoria



reserves, of which Manyeleti has open access to the Kruger National Park and is thus part of the Great Limpopo TFCA.

Population and sample size

The total population in the Mnisi study area is estimated at 40,000-50,000 individuals in approximately 8,500 households (Statistics South Africa, 2012). This study involved a stratified random sample of households within four purposively-selected villages: Athol, Gottenburg, Thlavekisa, and Utha (Figure 1). These villages were selected based on their close proximity to private and provincial game reserves as well as the presence or absence of a community health clinic (two with and two without). Within each village, each household was numbered using Google Earth™ images (Google Inc., Mountain View, CA, USA) and randomly selected using a random number generator (Microsoft Excel, Redmond, WA, USA). Sample size was determined by the following parameters for a population survey with random sampling: 2,300 total estimated households within the four selected villages (unit of analysis), an expected difference between villages of 15%, 95% confidence level, and 90% power. As a result, a total of 256 surveys were determined to provide sufficient statistical power (WinEpi, 2010).

Data collection method

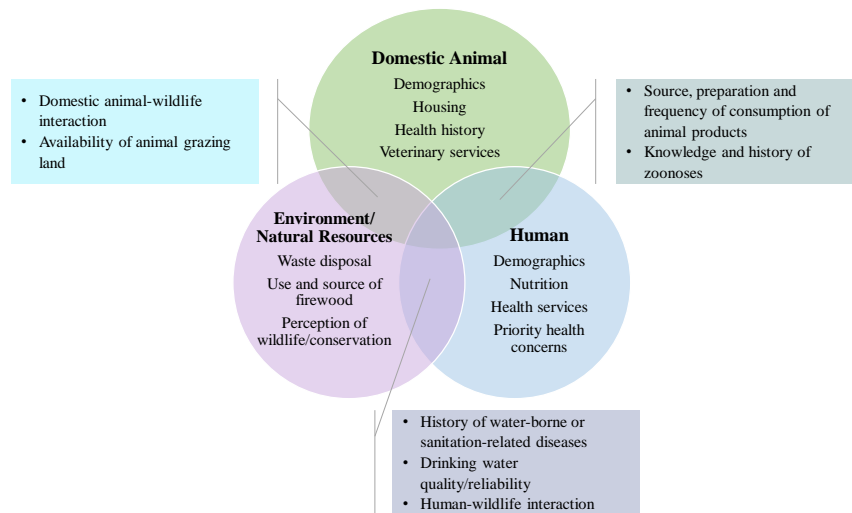
A cross-sectional, in-person survey using a structured questionnaire administered in the participants' household was used to obtain information from selected individuals. Responses were collected on personal digital assistants (PDAs) using SurveyToGo mobile survey software (Dooblo Ltd., Kfar Sava, Israel), which was previously deployed in the study area with success

(Madder *et al.*, 2012). The questionnaire underwent content validation by subject matter experts and community representatives to ensure appropriateness, relevancy, and cultural sensitivity of questions. A pilot questionnaire was trialed in a region not included in the final study site and adapted to maximize participant comprehension. All questionnaires were completed over four weeks between July and August 2013 by surveyors accompanied by a trained Shangaan-English translator employed by the Mnisi Community Programme. Potential participants were provided with an oral description of the study goals, the voluntary and confidential nature of their participation, and a time estimate for their involvement. Only those participants aged 18 years or older from whom consent was obtained were surveyed. This study was reviewed by the University of California, Davis Institutional Review Board and determined to be exempt from human subjects regulations. Ethics approval was also obtained through the University of Pretoria Research Ethics Committee, Faculty Humanities and permissions were granted by the Mnisi Traditional Council as well as village leaders. The information obtained from the questionnaires was recorded by the investigators in such a manner that subjects could not be personally identified, either directly or through identifiers linked to the subjects.

Survey design

The survey was designed to collect data on human and domestic animal population demographics, animal health and services, human health and services, wildlife, and environmental health (Figure 2). The survey employed a structured questionnaire, which included a combination of multiple choice (single answer), multiple selection, open-ended, and Likert scale questions. The first section, which focused on participant demographics, was

Figure 2. Schematic representation of the One Health framework used to design the topics to be included in the Mnisi study area questionnaire



designed to determine study eligibility and preferred language as well as to classify participants by education level, status within the household, occupation, and household size.

The second section aimed at describing the domestic animal composition of the household, the health priorities and history of those animals as described by the participant, the participant's perception of veterinary services in the community, and his/her knowledge of animal diseases and transmission. Participants were also asked about their consumption of animal products and the preparation of those products.

The third section of the questionnaire focused on human health factors, including nutrition, access to and satisfaction with available health care, and priority health concerns in adults and children as described by the participant. Participants were also asked about their household's health history, specifically the occurrence of diseases linked to animals, sanitation, and water.

The final section of the questionnaire focused on natural resources and environmental health, and included topics such as waste disposal, interactions with wildlife including rodents, source of and satisfaction with water, and participants' perceptions of conservation efforts in and around their community.

Data analysis

Descriptive statistics were used to summarize the main features of the data collected. Summary statistics including mean, median, standard deviation (SD), range, and maximum values for continuous variables and frequency and proportions for categorical variables were calculated. The chi-square test for homogeneity was used to test for village-level differences. Exploratory results suggested the importance of rodent sightings around the home. For that

reason, and because rodent-borne zoonoses have been identified to be prevalent and a major concern in the community (Quan *et al.*, 2014), we were particularly interested in identifying factors contributing to rodent presence at the household level. For this purpose, we used a multilevel logistic regression model with village as a random effect to identify factors contributing to observation or not of rodents at the household level (coded as 1/0, respectively). Rodent observation was considered as an ordinal variable with three response categories (daily, less than daily, never), but we found this categorization did not result in an improved model. The model is expressed as follows:

$$y_{ij} \sim \text{Bernoulli}(\pi_{ij}); \text{logit}(\pi_{ij}) = \beta_0 + \beta_1 X_{1ij} + \beta_2 X_{2ij} + \dots + \beta_k X_{kij} + u_j$$

where y_{ij} is the binary dependent variable—observation of rodents yes/no—for household i in village j ; π_{ij} is the expected probability of rodent observation within the household; β_0 is the intercept; $\beta_{1ij}, \beta_{2ij}, \dots, \beta_{kij}$ are the slopes; and u_j is the random effect, which accounts for clustering of households within villages. Model construction was initiated with a univariate analysis of hypothesized risk factors using a liberal p -value < 0.2 . Then a multilevel model was evaluated using forward selection. Quantitative variables were tested as predictors in their quantitative and binomial form, after being transformed using the median as the cut-off point. The best fitting multivariable model was assumed to be the one with the lower Akaike information criterion (AIC) and containing statistically significant predictors (p -value < 0.05). We also evaluated the effect of livestock ownership on the frequency of consumption of animal products by using a simple linear regression model. Statistical analyses were performed in SAS version 9.3 (SAS Institute, Cary, NC).

Table 1. Demographic characteristics of survey participants ($n = 262$) in 4 villages in the Mnisi study area, Mpumalanga Province, Republic of South Africa

	Athol	Gottenburg	Thlavekisa	Utha	Total
Sex					
Male, n (%)	17 (24)	12 (20)	16 (25)	12 (18)	57 (22)
Female, n (%)	55 (76)	49 (80)	48 (75)	53 (82)	205 (78)
Age, mean (range), in years	40.6 (19 – 83)	42.4 (18 – 100)	42.2 (18 – 82)	40.5 (19 – 83)	41.4
Household size†, mean (SD)	6.5 (3.7)	6 (2.9)	6.2 (3.3)	5.7 (2.9)	6.1 (3.2)
Head of household‡, n (%)	51 (71)	43 (79)	44 (69)	41 (63)	179 (68)
Unemployed, n (%)	58 (81)	40 (66)	45 (70)	47 (72)	190 (73)
Total surveyed, n (%)	72 (27)	61 (23)	64 (24)	65 (25)	262

†Total number of people living in the same dwelling space for at least 3 months and providing jointly for purposes of food

‡Self-identification as the head of the household

SD = standard deviation

Results

Demographic characteristics of participants

A total of 262 surveys were completed, representing an approximately equal proportion of respondents from each of the four selected villages ($n \sim 65$ per village). The participation rate exceeded 99%. Participant characteristics by village are summarized in Table 1. The majority (78%) of the respondents were female. The mean (\pm SD) household size among all participants was 6.1 ± 3.2 ; the mean number of children per household was 2.5 ± 1.8 , and the mean number of adults was 3.6 ± 2.3 . All participants spoke Shangaan, followed by English (23%) and Sotho (15%). The highest education level completed was Grade 12 (matriculation) for 82 respondents (31%); the next highest proportion of respondents (27%) reported completing no education ($n = 70$). Only seven respondents (3%), three of whom were female, reported receiving training beyond secondary school, including tertiary education or a certificate program. Of those respondents who had completed Grade 12 ($n = 89$), 79% were female and the mean age was 30 ± 7.7 . Seventy-nine percent of respondents reported receiving government assistance in the form of social grants (pension, child care, or disability).

Domestic animal demography and health

Domestic animal ownership statistics are described in Table 2. Seventy-two percent of all households surveyed reported owning at least one animal ($n = 189$). Sixty-eight percent of all households owned livestock species, including cattle, goats, pigs, or chickens; and 36% of all households included a dog or cat. Among the animal-owning households, the most frequently owned animals were chickens (76%), followed by dogs (42%), cattle (35%), goats (22%), cats

Table 2. Frequency and proportion of households surveyed in the Mnisi study area, Mpumalanga Province, Republic of South Africa ($n = 262$) reporting domestic animal ownership, by species, and the summary statistics for number of animals per household

Domestic animal ownership	Frequency (%)	Mean	Median	Maximum
Own at least one species	189 (72)			
Livestock	177 (68)			
Chickens	144 (55)	13.4	12	40
Cattle	66 (25)	12.4	7	78
Goats	42 (16)	6.9	6	17
Pigs	14 (5)	3.1	2.5	8
Ducks†	1 (0.4)	n/a	n/a	n/a
Pigeons†	1 (0.4)	n/a	n/a	n/a
Companion	95 (36)			
Dogs	80 (31)	2	1.5	6
Cats	23 (9)	2.3	2	5

†Number of animals was not collected for households owning ducks and pigeons

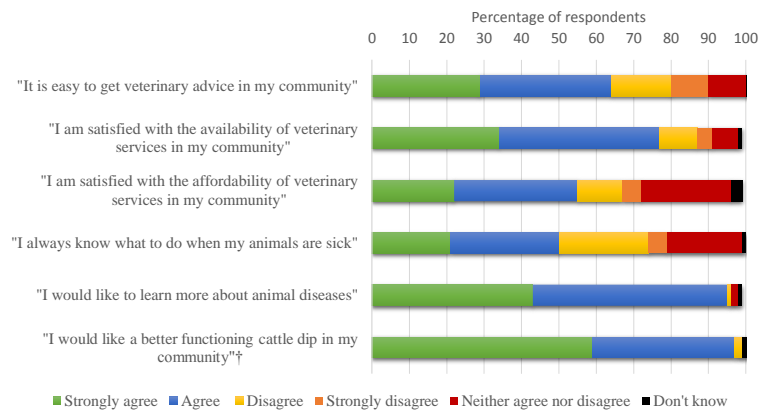
(12%), pigs (7%), ducks (<1%), and pigeons (<1%). Respondents with no formal education were more likely to own animals (one-sided chi-square test, $p = 0.0285$).

Livestock-owning participants were asked to identify the major health problems in their animals. Forty-nine percent described a condition in chickens characterized by swollen eyes, diarrhea, and sudden death. These clinical signs, used along with the Shangaan term “*mzungu*,” was consistent with Newcastle disease, a viral infection of domestic poultry caused by avian paramyxovirus type 1 that is endemic to parts of Africa (Ashraf *et al.*, 2014). Other major health problems identified in livestock included ticks and tick-borne diseases (11%), foot and mouth disease (FMD) (5%), rabies (1%), and lumpy skin disease (1%). With regard to preventive health, 42% of participants from livestock-owning households reported not administering or receiving vaccinations for their animals in the past 12 months. Cattle-owning participants ($n = 66$) were asked about health practices specific to cattle including the dipping or topical application of acaricides. With the exception of one individual, all participants reported that they dip their cattle for ticks. However, when asked how many times in the last month their cattle were dipped for ticks, 23 (35%) reported no dipping. Forty-three cattle-owning households (65%) reported that they use their own dip supplies. Using a five-point Likert scale, animal-owning participants ($n = 189$) were asked about their satisfaction with veterinary services in their communities; results are shown in Figure 3.

Satisfaction with human health services

Participants were asked whether they or a member of their household had utilized a community health clinic in the past 12 months. For those who did access a clinic ($n = 210$, 80%),

Figure 3. Stacked chart illustrating the perceptions of veterinary services among animal-owning survey participants in the Mnisi study area, Mpumalanga Province, Republic of South Africa ($n = 189$). †Pertains only to cattle-owning participants ($n = 66$)



individuals were asked whether they were satisfied with the quality of care they or the member of their household received. Ninety-four percent responded favorably. In addition, 85% of participants responded that they were satisfied with the accessibility of the clinic. The proportion of respondents who were satisfied with health clinic accessibility did vary by village (two-sided chi-square test, $p = 0.0002$). Those respondents who resided in villages without a community health clinic were more likely to be dissatisfied with clinic accessibility than respondents from villages with a clinic (24% vs. 6%). The primary barriers to health clinic access identified by respondents included cost of transportation to the clinic followed by being too ill/debilitated to travel.

Human health and nutrition

Priority health problems for both adults and children, as perceived by the surveyed participants, are summarized in Table 3. “Flu” was the most commonly reported health problem for both children and adults; symptoms described included coughing, sneezing, runny nose, fever, and/or chills.

Only 3% of participants ($n = 9$) reported a history of an illness linked to animals in either themselves or a household member. When asked to describe the illness, surveyed individuals reported internal parasites, tuberculosis, rabies, malaria, and pruritus/skin lesions. Participants were not asked to differentiate between *Mycobacterium tuberculosis* and *Mycobacterium bovis*. Eight percent ($n = 22$) reported a history of an illness linked to poor water quality; symptoms included diarrhea, vomiting, headaches, and swollen hands and feet.

All surveyed individuals were asked about their diets and frequency of consumption of selected food items. The most frequently consumed food item was *pap*, a traditional ground

Table 3. Priority health problems in children and adults in the Mnisi study area, Mpumalanga Province, Republic of South Africa as identified by survey participants ($n = 262$)

Children (n)	Adults (n)
Flu† (215)	Flu (93)
Diarrhea (82)	Hypertension (69)
Chickenpox (35)	Back/joint pain (68)
Itchy scalp (19)	HIV (62)
Vomiting (11)	Headaches (51)
Fever (11)	Diabetes (49)
Wounds (9)	Tuberculosis (43)
Respiratory (coughing, asthma) (8)	Diarrhea (17)
Headaches (7)	Cancer (13)

†Participants used “flu” to describe an illness with coughing, sneezing, runny nose, fever, and/or chills. Etiology was not confirmed.

maize porridge, eaten on average 13.3 ± 4.4 times per week. Bread was consumed 5.9 ± 2.9 times per week, followed by poultry at 4.1 ± 2.8 times per week, and eggs and fruit both consumed 3.1 ± 2.7 times per week. Less common sources of protein included fish, beef, goat, and wild animals (predominantly impala, duikers, and scrub hares). A small, yet statistically significant relationship existed between poultry and red meat (beef, goat, pork) consumption and the total number of chickens and cattle owned, respectively. Household poultry consumption increased 0.04 times per week for every increase by one in the number of chickens owned ($p = 0.0244$); more frequent red meat consumption in a household, defined as more than monthly, increased by 4% for every increase by one in the number of cattle owned ($p = 0.037$). A statistically significant relationship between consumption of eggs and milk did not exist between poultry and cattle ownership, respectively.

Zoonotic disease knowledge and practices

All participants were asked about their perception of disease transfer from animals to humans. Sixty-one percent of those surveyed thought that some diseases of animals could be passed to humans. For these participants, open responses regarding what diseases could be passed from animals to humans included: rabies, food-borne diseases, foot and mouth disease, Newcastle disease, skin conditions consisting of pruritus and alopecia, tuberculosis, influenza, chickenpox, and joint problems from a new “fast-growing breed” of chickens; the most common response was “I don’t know.” The animal species of most concern with regard to disease transmission to humans was dogs ($n = 125$), followed by cattle ($n = 25$), and cats ($n = 11$).

Forty-eight percent of respondents thought that how you handle or prepare food products from animals could determine whether you got sick. Among those participants who reported

owning milking animals, such as cattle or goats ($n = 92$), 36% drank the milk from their animals. Of those individuals, 24% preferred to drink their milk fresh (not boiled). For those participants who reported boiling their milk, their reasons for boiling included to “kill germs” and to “get rid of the smell.”

Eighty-five percent ($n = 224$) of those surveyed believed that shared water sources among people, livestock, and wild animals could be a health risk. However, 118 (45%) of individuals reported that they collect water for their household from places where animals are known to use the water. A similar proportion reported washing clothes where animals (domestic or wildlife) drink the water. There was not a statistically significant relationship between knowledge of potential health risks of shared water and water collection behaviors (two-sided chi-square test, $p = 0.877$).

Environmental health

Individuals were asked about their perception of drinking water reliability and safety using a five-point Likert scale. The percentage of respondents who perceived water reliability favorably differed by village (two-sided chi-square test, $p = 0.0033$). Utha community members perceived water reliability least favorably; Gottenburg residents perceived water reliability most favorably. Water safety was generally recognized as favorable across all villages with 117 (45%) responding “strongly agree” and 131 (50%) responding “agree.”

All participants were asked about their utilization of disposable diapers. For those that had a young child in the household, 80% reported that they used disposable diapers. Among those

individuals, the disposal methods included: burning (44%), throwing in pit toilet (22%), burying (21%), throwing in the bush (10%), and throwing in/around the river (6%).

Firewood was used for cooking energy in 94% of households. The primary source of firewood was self-collection from the bush (96%). Forty percent ($n = 106$) of households reported using cattle manure for either fire or fertilizer.

Wildlife (including rodents) and conservation

Seventy-six percent ($n = 198$) of those surveyed reported seeing rodents in and around their home; of those, 62% reported daily observations, 27% reported observations 1-6 times per week, and 9% reported monthly observations. Control techniques included rodenticides, glue traps, cats, beating with sticks, and chasing away. Significant risk factors for rodent sightings included high household size (defined as ≥ 6 persons per household) (OR = 2.742, 95% CI = 1.473 – 5.104, $p = 0.0016$) and chicken ownership (OR = 2.059, 95% CI = 1.113 – 3.811, $p = 0.0217$). Cat ownership was associated with a decreased risk of rodent observations in and around the home (OR = 0.287, 95% CI = 0.107 – 0.767, $p = 0.0131$) (Table 4). No interaction terms were found to be significant.

Participants were asked about wildlife interactions with household members, domestic animals, and crops. Human-wildlife interactions were predominantly associated with hunting or with trapping/killing rodents. Livestock-wildlife interactions included shared or neighboring grazing areas with antelope species, buffalo, and wildebeest; predation of smaller livestock such as goats and calves by cheetah, hyenas, and lions; and snake bites on chickens. Companion animal-wildlife interactions included predation on rodents by cats and dogs used for hunting

Table 4. Independent predictors, beta coefficients, odds ratios (OR) and 95% confidence intervals (CI) obtained for univariable and multivariable multilevel logistic regression model (with village as random effect) of domiciliary rodent observation (yes/no) in households within the Mnisi study area, Mpumalanga Province, Republic of South Africa

Predictors (<i>n</i>)*	β	Univariable OR	95% CI	<i>p</i> -value	β	Multivariable OR†	95% CI	<i>p</i> -value
X ₁ ‡. Household dwellers coded as 1 - \geq 6 (median) (136), 0 - $<$ 6 (126)	0.9520	2.591	1.567 – 5.031	0.0015	1.0056	2.734	1.461 – 5.114	0.0018
X ₆ . Chicken ownership coded as 1 – yes (144), 0 – no (118)	0.6828	1.979	1.118 – 3.505	0.0191	0.7213	2.057	1.108 – 3.818	0.0224
X ₈ . Cat ownership coded as 1- yes (23), 0 – no (239)	-0.7658	0.465	0.191 – 1.132	0.0917	-1.2427	0.289	0.107 – 0.777	0.0141

Fit statistics for multivariable model								
σ_j^2 (SE)						0.1264 (0.1596)		
AUC (ROC)						0.71		

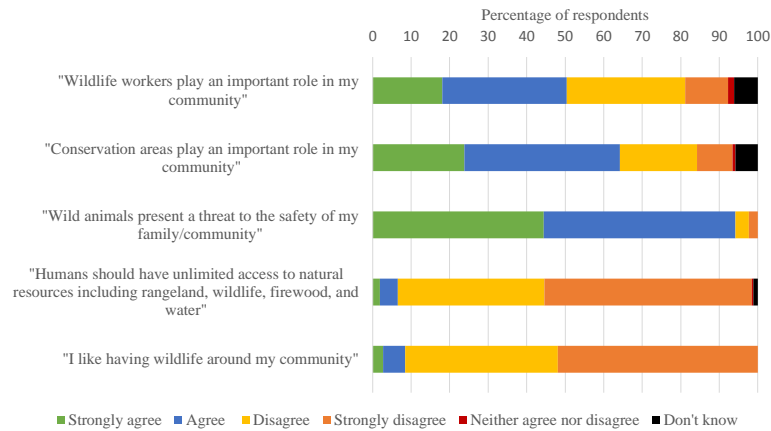
*Number of observations in each class of the predictor variable

†Final multivariable model included only those variables that were significant ($p < 0.2$) in the univariable model and significant ($p < 0.05$) in the multivariable model

‡Variable X_l was tested both as continuous and binomial ($0 = \text{value} < \text{median}$; $1 = \text{value} \geq \text{median}$) variables to determine the best model fit

Model fit statistics: σ_j^2 = variance of the random effect; SE = standard error; AUC = area under curve; ROC = receiver operating characteristic

Figure 4. Stacked chart illustrating the perceptions of wildlife and conservation among survey participants in the Mnisi study area, Mpumalanga Province, Republic of South Africa ($n = 262$)



small mammals such as scrub hares and duikers. Thirty-eight percent ($n = 99$) of those surveyed reported wildlife contact with crops, predominantly by elephants ($n = 24$), rodents and hares ($n = 21$), baboons ($n = 16$), and birds ($n = 13$).

Seventy-four percent of participants agreed that diseases affecting wild animals could be transmitted to domestic animals; of the remaining, an equal proportion disagreed and responded, “I don’t know.” Participants’ perceptions of wildlife and neighboring conservation areas are shown in Figure 4. When asked about advantages of adjacent conservation areas, the primary responses included employment opportunities, recreation, wildlife conservation, protection from wildlife, educational opportunities, and donations. Disadvantages included wildlife damage to crops and predation of livestock, safety risks to community members, unfair employment practices, wildlife poaching/crime, and restricted access to natural resources such as grazing land and firewood.

Discussion

This study describes a method by which to initiate integrated health research and planning at the community level that combines community engagement and the OH approach. The result is a comprehensive profile of animal and human demographics and health priorities and a description of environmental practices including waste disposal, water collection as well as wildlife-domestic animal-human interactions. With regard to animal demography, 72% of all surveyed households reported owning at least one animal and 68% reported owning livestock. This proportion of livestock ownership is consistent with similar rural, resource-poor communities (Livestock in Development, 1999; Pica-Ciamarra *et al.*, 2011). The majority of animal-owning

respondents were satisfied with the availability and affordability of veterinary services within the community. In the Mnisi study area, there is no privatized animal health care. Veterinary care is made available through the state veterinary service and the UP-run Hluvukani Animal Health Clinic which provides clinical services at a subsidized rate as part of student training. Cattle-owning participants across all villages, however, revealed a distinct need for a better-functioning cattle plunge dip for the administration of acaricides to prevent the transmission of tick-borne diseases and injury produced by tick bites. In this region, tick-borne diseases of cattle, including babesiosis, anaplasmosis, and heartwater, are prevalent (Masika *et al.*, 1997; Rikhotso *et al.*, 2005). The economic impact of ticks and tick-borne diseases is great and can be expressed in terms of mortality, production loss, cost of control, and, in some cases, movement restrictions of animals (Mbatia *et al.*, 2002). In addition, specific cattle ticks (*Amblyomma hebraeum*) can carry African tick bite fever, the most prevalent rickettsial disease in South Africa among humans (Frean *et al.*, 2008). The Mnisi study area is in a FMD protection zone with vaccination, and the South African government (Mpumalanga Veterinary Services) mandates weekly inspection of cattle at registered facilities. At this inspection, cattle are typically exposed to an acaricide by plunge dipping, but sometimes pour-on treatment is used in the absence of a dip tank at the inspection point. Frequent dipping was introduced to prevent cattle losses from the buffalo-borne corridor disease (*Theileria parva*) which is transmitted mainly by the brown ear tick (*Rhipicephalus appendiculatus*), as well as to serve as an incentive for farmers to participate in the weekly inspections related to FMD control policy. However, due to government budget restraints affecting water supply infrastructure to plunge dip tanks and even villages in especially the dry season, weekly dipping frequency is sometimes interrupted. The survey revealed that one-third of cattle owners had not dipped their cattle for ticks in the past month. While the

survey was conducted in the winter months when ticks are less prevalent, the dissatisfaction with cattle dip facilities is likely due, in part, to this lack of consistency in dipping frequency. Prior studies in the area have shown that intensive acaricide application may be unnecessary and that a strategic regimen, one that considers relative tick abundance, may be effective in producing endemic stability of tick-borne diseases in communally-grazed cattle (Rikhotso *et al.*, 2005). If well-communicated, a strategic tick control regimen could be favored among farmers in the Mnisi study area due to some of the documented disadvantages of intensive cattle dipping, including physical injuries, stress, and labor costs (Rikhotso *et al.*, 2005).

Among the livestock-owning respondents, a disease of poultry consistent with Newcastle disease was the most prevalent health concern of food-producing animals described. Chickens are a valuable protein source for resource-poor South Africans as they are inexpensive to keep. However, given the free-range nature of chickens in this region, the risk of infectious disease outbreaks among poultry is high and difficult to control without proper interventions (Thekiso *et al.*, 2004). Newcastle disease is a viral disease, and although it is endemic to South Africa, poultry losses are largely preventable with proper vaccination (Thekiso *et al.*, 2004). Preventive health measures such as vaccination and segregation of sick animals could be effective tools in these communities. Improved poultry health could have significant implications for public health and nutrition given the reliance on eggs and poultry for protein in the Mnisi study area.

This study identified a linkage between human nutrition and animal ownership. Households owning larger flocks of chickens and herds of cattle reported an increased consumption of poultry and red meat, respectively. The association between animal ownership and likelihood of consuming animal source foods has been previously demonstrated by Thumbi *et al.* (2015), albeit with egg and milk consumption. Our study did not show a statistically significant

relationship between livestock ownership and egg or milk consumption. This finding may suggest a difference in dietary preferences or that these animal products are used in an alternative way, such as an income source. Although we identified an association between human nutrition and animal ownership, it is important to consider the possible confounding effect of household socioeconomic status, including non-livestock income sources, which we did not measure in our study and which may be positively associated with both animal ownership and household consumption of animal products (Thumbi *et al.*, 2015). Future surveys in the study area should consider including household income as it is a possible explanatory or confounding variable.

This survey highlighted many opportunities to improve animal health education in this community, not only pertaining to animal diseases for the sake of improving production and perhaps livelihoods, but also for improving public health. Zoonotic diseases such as rabies, tuberculosis, and brucellosis continue to pose a threat to public health in many parts of South Africa, including the Mnisi study area (Marcotty *et al.*, 2009; Conan *et al.*, 2015). Few households reported a history of an illness that could be linked to animals; however, zoonoses are likely underdiagnosed and misinterpreted in this community (Quan *et al.*, 2014). The perception by the survey respondents of malaria as a human disease linked to animals may indicate a misunderstanding of the zoonotic potential of malarial parasites and, thus, an opportunity for health education in this community. Additionally, in this study, one-quarter of those who drank the milk from their own animals preferred to drink the milk fresh as opposed to boiling first. The handling and consumption of fresh milk can be a source of zoonotic tuberculosis and brucellosis (Marcotty *et al.*, 2009). This health risk is preventable with proper education. Increased education about animal diseases was desired by 96% of animal-owning survey respondents. In this study, animal-owning individuals were more likely to have no formal

education; thus, health education targeted towards animal-owning community members may be a sound approach to addressing critical infectious disease control points within the Mnisi study area.

With some public health risks, such as the collection and household utilization of water from sources shared by domestic animals and wildlife, it was evident that knowledge of health risks was not sufficient to alter behavior. Therefore, it is likely that, with regard to this particular public health issue, there are other factors to consider, including availability of water by established taps or proximity to such taps. Participants from Gottenburg revealed the highest satisfaction with water reliability, therefore follow-up studies could evaluate location-specific factors affecting water supply.

Prior to this survey, there was no knowledge on the frequency of utilization of disposable diapers or disposal practices. This study revealed that the majority of households with young children utilized disposable diapers and that nearly half of these households opted for burning the waste; however, throwing the waste in the bush or near the river was also described. Not only is the degradation process for disposable diapers slow, the contamination of waterways by human feces is a public health concern. As the frequency of these practices is likely to increase, future research that focuses on evaluating water quality in relation to waste disposal may become a priority.

With regard to satisfaction with available public health services, overall the respondents were very satisfied with the community health clinics; however, the survey revealed a statistically significant difference between those respondents residing in villages with a community health clinic versus those without a clinic. Those individuals from villages without a clinic who cannot afford transport or who are too ill to travel may not be able to access care. Despite the health

services being provided by the government at no cost, if an individual cannot access the clinic, they are not able to benefit from the services. The survey revealed a need for enhanced transportation options or mobile health service delivery to improve access to disadvantaged members of the community.

Due to the random selection of surveyed households and the high participation rate, results of this study are likely highly generalizable to other households within the four villages. However, it is probable to assume that our survey demographics likely over-represented unemployed, less educated household members. The survey included a skewed distribution of respondents by sex, education, and employment status. Surveys were conducted during the working hours of 8 a.m. – 5 p.m. on weekdays when most employed household members would not be available for questioning. In addition, it is likely that these individuals would be less aware of household practices pertaining to livestock care which are typically performed by males. Also, as this study relies on self-reported disease and health data, responses were subject to recall bias. Correlating these data with human and animal medical records would be one method by which to validate participant responses. Although the objective of the current study was largely descriptive of a single defined population, a lack of a comparison group may be considered a limitation. Follow-up studies should consider evaluating significant associations in additional communities.

In this study, “flu” was described as a priority health problem in both children and adults. It is important to acknowledge that responses may have been influenced by the seasonality of data collection as all surveys were conducted during the winter months. Future studies could evaluate the effect of temporality on human and animal health priorities. Further, participants described flu symptoms and not necessarily a diagnosis of influenza. Participants used “flu” to describe illness with coughing, sneezing, runny nose, fever, and/or chills. Etiology was not confirmed.

Diagnostic capability at community clinics is limited, therefore, a targeted effort should be made to determine the etiology of observed human and animal illnesses and the concurrent collection of economic, social, and biological determinants of health that have proven to be significant in this study. Zoonoses are likely underdiagnosed, therefore, additional studies focused on quantifying the burden of zoonotic diseases in this population are warranted.

Wildlife are an important potential reservoir for zoonoses, particularly peri-domestic wildlife such as rodents which were observed in three-quarters of all surveyed households. The observation of rodents around the home has been shown to be an independent risk factor for zoonotic diseases such as leptospirosis, regardless of direct contact (Sarkar *et al.*, 2002). In the current study, household rodent sightings were frequent across all villages and significantly associated with increased household size and chicken ownership, presumably due to increased food availability and/or more suitable rodent habitat (*i.e.*, poor external hygiene). Bonner *et al.* (2007) demonstrated that poor external hygiene may act as a risk factor for domiciliary rodent infestation and the transmission of rodent-borne zoonoses. Another possible explanation for the observed association between household size and rodent sightings is the increased likelihood of witnessing and reporting of rodent observations by household occupants to the adult survey respondent. The presence of a cat in the household significantly reduced the risk of household rodent sightings in our study. Endemic zoonoses such as leptospirosis can present with non-specific symptoms, thus posing a challenge to human and veterinary clinicians in resource-poor areas (Halliday *et al.*, 2015). Thus, regionally-specific risk factors such as these may be very helpful in refining diagnostic and treatment algorithms, leading to improved disease management.

Over 90% of study participants were in favor of the regulation of access to natural resources, including rangeland, wildlife, firewood, and water, indicating a strong sense of environmentally sustainable practices. In addition, the majority of participants believed the conservation areas played an important role in their community. Advantages of the adjacent conservation areas included economic (*e.g.*, employment opportunities, donations) and non-economic (*e.g.*, recreation, education, wildlife protection) factors. Prior studies involving communities adjacent to parks indicate that perceptions of biodiversity conservation are strongly related to locally-perceived benefits (Anthony, 2007; Vodouhê *et al.*, 2010). Thus, an environmentally aware, conservation-conscious community is more likely to arise from one that benefits from the activities directly. Despite this appreciation for wildlife conservation, most survey participants indicated a dislike for wildlife around their community and a perceived threat by wildlife to personal safety. Together, these results suggest a preference by the community for a dichotomous approach to wildlife management, one that separates wildlife from humans, as opposed to one that is more integrative. This paradox has been previously described in communities adjacent to Kruger National Park (Anthony, 2007). It must be added that perceptions regarding models for the potential integration of, for instance, livestock and wildlife, in parts of the landscape where it might be feasible, were not explicitly tested. These findings, however, demonstrate the complexity of the landscape and the need for a broad, social-ecological approach to health.

Conclusion

In low-income countries, the linkages between livestock keeping and human health are complex and include both positive (*e.g.*, animal source food availability) and negative (*e.g.*, zoonotic and

food-borne diseases) effects (Nicholson *et al.*, 2003; Randolph *et al.*, 2007). To improve health at the community level, the goal must be to maximize the positive linkages while minimizing the negative effects of the human-animal connections. Future steps should include the identification of priority diseases in humans and domestic animals, the quantification of the burden of these diseases, and the identification of their risk factors. This type of detailed data which summarizes agricultural practices, food consumption and water-use habits, illness in animals and people, and access to health care can be used to tailor education efforts for priority diseases and pandemic prevention (Mazet *et al.*, 2009). A healthier Mnisi community, part of a region delicately balancing on the fringe of the Great Limpopo TFCA of eastern South Africa, would provide benefits not only within the boundaries of the community but beyond the fences, potentially impacting health and conservation efforts in the regional network of protected areas.

Conflict of interest statement

The authors declare no personal or financial conflict of interest.

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