Mapping potential amplification and transmission hotspots for MERS-CoV, Kenya

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Running Title: Potential MERS-CoV hotspots in Kenya

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Abstract

Dromedary camels have been implicated consistently as the source of Middle East Respiratory Syndrome – Corona Virus (MERS-CoV) human infections and attention to prevent and control it has focused on camels. To understanding the epidemiological role of camels in the transmission of MERS-CoV, we utilized an iterative empirical process in Geographical Information System (GIS) to identify and qualify potential hotspots for maintenance and circulation of MERS-CoV, and produced risk-based surveillance sites in Kenya. Data on camel population and distribution was used to develop camel density map while camel farming system were defined using multi-factorial criteria including the agro-ecological zones (AEZs), production and marketing practices. Primary and secondary MERS-CoV seroprevalence data from specific sites was analyzed and location-based prevalence matching with camel densities was conducted. High-risk convergence points (migration zones, trade routes, camel markets, slaughter slabs) were profiled and frequent cross border camel movement mapped. Results showed that high camel-dense areas and interaction (markets and migration zones) were potential hotspot for transmission and spread. Cross-border contacts occurred with in-migrated herds at hotspot locations. AEZ differential didn't influence risk distribution and plausible risk factors for spatial MERS-CoV hotspots were camel densities, previous cases of MERS-CoV, high seroprevalence and points of camel convergences.

Although Kenyan camels are predisposed to MERS-CoV, no shedding is documented to date. These potential hotspots, determined using anthropogenic, system and trade characterizations should guide selection of sampling/surveillance sites, high risk locations, critical areas for interventions and policy development in Kenya, as well as instigate further virological examination of camels.

Keywords: MERS-CoV; camel; Kenya; hotspot; transmission; risk

Introduction

Emerging and re-emerging infectious diseases continue to threaten global health security. Zoonotic diseases or pathogens account for 70 percent of emerging infectious diseases (EIDs) and 60 percent of human pathogens/diseases (Woolhouse & Gowtage-Sequeria 2005; Jones et al. 2008). Major zoonotic EIDs have occurred over the last twenty years including but not limited to Middle East respiratory syndrome coronavirus (MERS-CoV) (Ntoumi et al. 2016). MERS-CoV was first diagnosed in human in 2012 in Saudi Arabia (Zaki et al., 2012) as a novel zoonotic virus responsible for more than 1,918 laboratory confirmed cases including 729 fatalities by February 2017 (WHO, 2016; FAO, 2017).

The epidemiology of MERS-CoV is not well established but epidemics in humans have occurred sporadically with geographic range restricted to the Middle East/Arabian Peninsula (Khalafalla et al. 2014; Sabir et al. 2016). In addition, most human cases have been associated with healthcare settings, with a fifth of virus detections reported among healthcare workers (Mackay and Arden, 2015a, 2015b). Travel related MERS-CoV links have also been established and these remain a threat to other regions in view of rapidity and intensity of travels (Fanoy et al. 2014). Since the discovery of MERS-CoV in 2012 (Zaki et al. 2012), serologic and molecular evidences have demonstrated that the virus in dromedary camels is genetically very similar to MERS-CoV in humans, hence the conclusion that dromedary camels may serve as reservoirs for human infections (Nowot & Kolodziejek 2014; Dudas & Rambaut 2016). Bats are also considered as the likely primary source of zoonotic *beta-coronaviruses* (Memish et al. 2013).

In recent past, the role of camels as major contributors to food security and livelihood in the arid and semi-arid parts of Sub-Saharan and North Africa has been threatened by the emergence of MERS-CoV (Jores 2015), not because the virus cause severe disease in camels but because of potential loss of export markets of camel products due to avoidance by humans. In addition, Somalia, Sudan and Ethiopia, with high seroprevalence of MERS-CoV antibodies (Müller et al. 2014) sometimes move their camels through Kenya. Hence, attention to prevent MERS-CoV has focused on camels.

Although no human case of MERS-CoV has been reported in Kenya, serologic evidence for circulation of the virus in camels dates back to 1992 (Corman et al. 2014).

To date, information on the epidemiology of MERS-CoV in humans, animals and the environment is scanty and details on the virus persistence and transmission (animal to animal, animal to human, human to human, and in the environment) is lacking (McKay & Arden 2015a). The exact mode of transmission to humans from camels and other possible animal sources remains undefined (Ruesken et al. 2013; McKay & Arden 2015a, 2015b; Adney et al. 2016). However, sequencing data has suggested that MERS-CoV originated from bat ancestors and may have undergone a recombination event in the spike protein, possibly in dromedary camels in Kenya including other Eastern African regions before its exportation to the Arabian Peninsula along the camel trading routes (Omrani et al. 2015).

The Greater Horn of Africa (HOA) covering Djibouti, Eritrea, Ethiopia, Kenya, Somalia, South Sudan, Sudan, Uganda is home to over 70% of the world camel population (Farah et al. 2004; FAOSTAT 2015). The Region is a major exporter of live camels and meat to Egypt and the Gulf Cooperation Council countries of Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and United Arab Emirates (Mahmoud 2010). Egypt is a major consumer of a significant amount of camel meat from Ethiopia, Eritrea and the Sudan, and most of the "Ethiopian camels" are thought to originate from or have spent part of their lifetime grazing in Kenya and Somalia.

The detection of MERS antibodies in Camels in HOA, a region with significant trade links to infected countries, has triggered the need for greater eco-epidemiological understanding of MERS-CoV in the HOA (Corman et al., 2014; Muller et al., 2014; Deem et al., 2015). Already regional and country efforts have been initiated. The USAID's Emerging Pandemic Threats (EPT-2) programme of GHSA has extended financial support to Kenya, Ethiopia, Egypt and Jordan to undertake MERS-CoV surveillance in livestock and wildlife in order to generate useful information for prevention and control.

To understand the epidemiology of the virus in Kenya, the delineation of hotspots and risk mapping of the camel production zones are important for surveillance, rapid response and policy formulation and to

reduce the risk of long distance transmission of the virus. In addition, in view of the limited resources available for livestock disease surveillance, the mapping will enable the country to prioritize and focus surveillance, understand trade patterns and evaluate risk behaviours. This study was carried to identify and map MERS-CoV potential hotspots along the camel value chain in Kenya using literature reviews, empirical and anecdotal evidences, expert opinion, field surveys and interviews.

Materials and Methods

Extensive literature review on camel production and marketing in Kenya was carried out to analyze camel population and densities, document existing farming and marketing practices and generate data to map stakeholders involved in the camel value chain and understand the global perspective. The review also revealed knowledge gaps and the combination of approaches mentioned above was used to arrive at criteria for risk mapping.
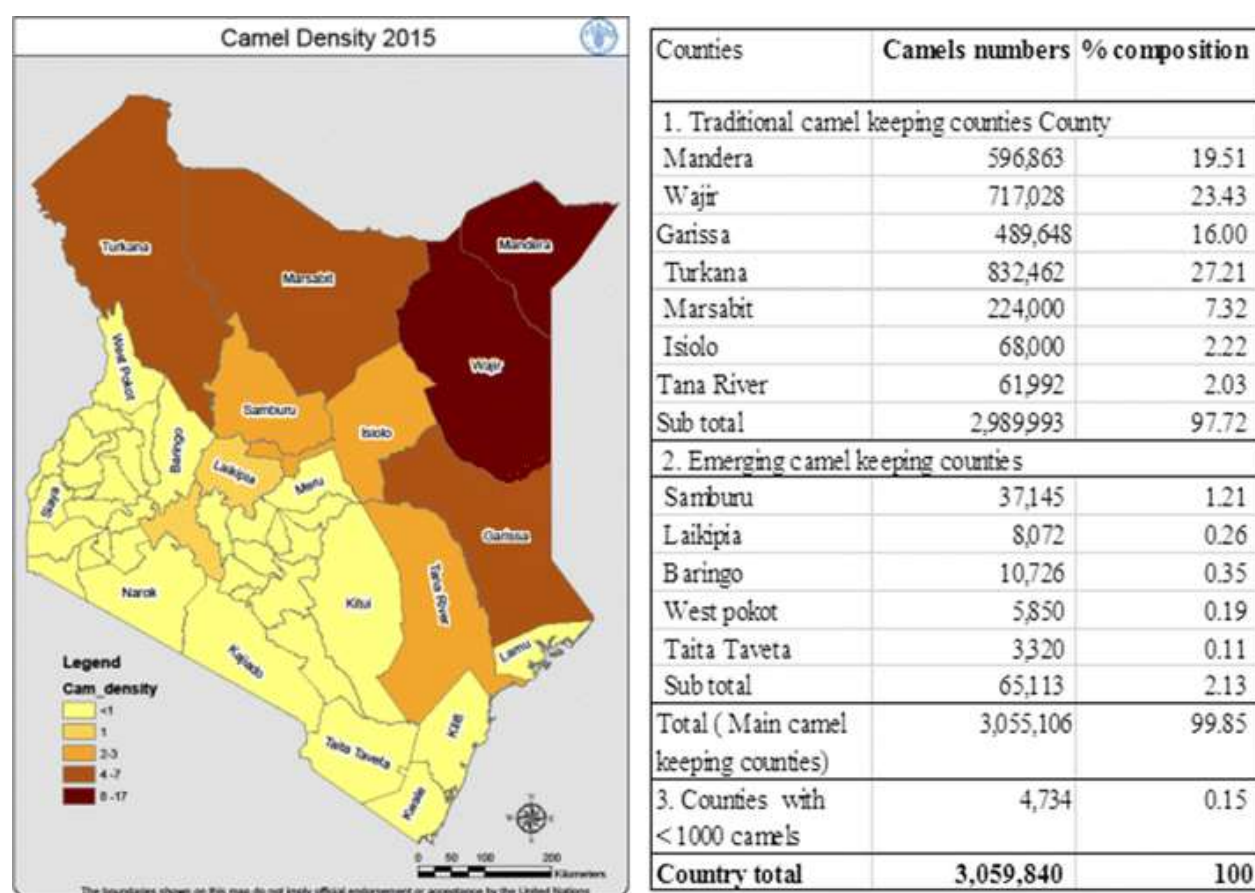
Data mining

Global-level data on the status of infection, transmission and affected/implicated species of animals for MERS-CoV as well as previous seroprevalence studies among camels in Kenya were mined for useful quantitative and qualitative datasets. Furthermore, field data on the camel production systems in Kenya, marketing practices, population dynamics and densities as well as on trade networks, linkages and movement routes for camels in the HOA were collected and supplemented by available peer-reviewed and grey literature (FAO, 2016). Documents were obtained from government repositories, commissioned reports, conference papers, institutional analyses and peer-reviewed literature using search engines (Google Scholar and PubMed). Duplicate reports were removed from the search and data search and filtration was carried out by two independent researchers leaving a total of 54 documents for evaluation. Relevant stakeholders were interviewed to clarify sectoral data. Country and county-level camel populations (2015 estimates) were obtained from Directorate of Livestock Production (DLP), State Department of Livestock, Ministry of Agriculture, Livestock and Fisheries (MoALF).

Field data collection

Between July and December 2016, field evaluations, rapid appraisals and validation studies were carried out in Laikipia, Isiolo and Marsabit Counties on camel production systems, marketing, trade volumes and migration routes. Using analytical hierarchical method in decision making to generate consensus opinions (Saaty, 2008), semi-structured questions and check list were utilized to gather data from key informants: County veterinary staff (n = 5); County Animal production staff (n = 3); Meat inspectors (n = 1); Livestock Market Association members (n = 1); Camel traders (n = 13); Herders (n = 4); Livestock marketing cooperative (n = 1); Camel meat trader (Butcher) (n = 1); Primary marketers (n $\approx$ 150 to 250 persons); Secondary marketers (n $\approx$ 300-400 persons); other key informants (n = 2); total (n = 481 – 681 persons) . The data obtained were triangulated by independent field visits to six (6) selected secondary markets (two in each of the three counties) with additional data gathered from two camel slaughter slabs. A Market Profiling Tool (MPT) (Supplementary material 1a) was developed and utilized to capture market-level quantitative and qualitative data. Description of the infrastructure and biosecurity status of the six markets and two slaughter slabs was achieved through observations of the investigators.

Trade and migration routes were updated through participatory geographical information systems (pGIS) involving focused group meetings (FGM) with randomly selected local community members (n = 30) to cross-validate the data above. Specifically, ten members of each community were chosen based on gender/age disaggregation including four men, three women and three youths. This selection also cut across functional roles (men: rearers/owner, take camels on long-distant travels and responsible for monies arising from camel sales; women: do daily chores around camels in the households like milking restraints and processing/marketing of bye-products; youth (both sexes inclusive) usually drive the camels daily to the fields/markets). Each group listed major markets and other features relevant to the camel sector such as watering points and pasture fields. Community base maps was provided with key topographic features in mini-workshops and missing features were compiled based on visual routes used for trade and within-country migration. Each group made presentations which was critiqued by group

members before group consensus was reached. Communities' views and perception on the goe-spatial-temporal attributes per community was obtained through non-structured interviews and the outputs of FGM. All spatial locations and features provided were geocoded using Epicollect 5® (Imperial College, London) through follow-up field walks and mapping with the key informants. All geospatial data were again cross-matched with details obtained from the interviews. Based on the mined data, interviews, FGM and field walks and county-level data on camels, density map was created (Figure 1).

Counties	Camels numbers	% composition
1. Traditional camel keeping counties County		
Mandera	596,863	19.51
Wajir	717,028	23.43
Garissa	489,648	16.00
Turkana	832,462	27.21
Marsabit	224,000	7.32
Isiolo	68,000	2.22
Tana River	61,992	2.03
Sub total	2,989,993	97.72
2. Emerging camel keeping counties		
Samburu	37,145	1.21
Laikipia	8,072	0.26
Baringo	10,726	0.35
West pokot	5,850	0.19
Taita Taveta	3,320	0.11
Sub total	65,113	2.13
Total (Main camel keeping counties)	3,055,106	99.85
3. Counties with <1000 camels	4,734	0.15
Country total	3,059,840	100

Figure 1. Map of camel population densities in Kenya and Table 1 Camel population in major camel keeping counties. *Source*: Director of Livestock production (DLP) 2015 livestock population estimates.

Data Analysis

The tabular data (Table 1) and DLP-MoALF camel population data were linked with spatial data and using map calculator, the camel density per county was developed (Figure 1). Camel production systems were analyzed and reclassified based on the different agro-ecological zones of the country, and also disaggregated by Counties. Agro-ecologically, the country has been zoned into the following: I (Humid with mean annual rainfall of 1100-2700mm), II (Sub-humid with mean annual rainfall of 1000-1600mm), III (Semi-humid with mean annual rainfall of 800-1400mm), IV (Semi-humid to semi-arid with mean annual rainfall of 600-1100mm), V (Semi-arid with mean annual rainfall of 450-900mm), VI (Arid with mean annual rainfall of 300-550mm) and VII (Very arid with mean annual rainfall of 150-350mm) (Sombroek et al., 1982).

Table 1. Camel production systems per agro-ecological zones and population growth and projection, 2009-2015

Production system				Agro-ecological zones (Climate type)		Locations		
Traditional Pastoralism				VII, VI, V (Semi Arid to very Arid)		Mandera, Wajir, Garissa, Tana River, Marsabit, Turkana. Baringo, Samburu Isiolo, Laikipia ,Kajiado		
Semi-Sedentary system including ranching and Peri-urban camel production				V (Semi-Arid)		Isiolo, Laikipia ,Kajiado,		
Commercial ranching				V (Semi-Arid)		Laikipia , Taita Taveta		
Camel population growth trend in Kenya between 2009 and 2015								
Year	2009	2010	2011	2012	2013	2014	2015*	Mean annual growth (%)#
Estimated	2,971,111	3,030,600	3,091,200	2,864,732	2,899,244	2,937,262	3,059,840	0.56%
Percentage difference (%)	NA	2.00	2.00	-7.33	1.20	1.31	4.17	3.36 (absolute growth)

*Source: FAOSTAT (2015). http://faostat3.fao.org, *2015-Estimates from Directorate of Livestock Production. #Note that the total absolute growth for the seven-year period was 3.36%.*

Details of persons who participated in VCA & pGIS interviews and their functional roles: County veterinary staff (n = 5): provision of animal health services and regulation of diseases control; County Animal production staff (n = 3): provision animal production advisory services; Meat inspectors (n = 1): meat hygiene services; Livestock Market Association members (n = 1): management of livestock markets; Camel traders (n = 13): trade in camels; Herders (n = 4): grazing, security , milking , watering of camels; Livestock marketing cooperative (n = 1): promotion of efficient livestock marketing and development; Camel meat trader (Butcher) (n = 1): slaughter and sale of camel meat; Primary marketers (n ≈ 150 to 250 persons); Secondary marketers(n ≈ 300-400 persons); other key informants (n = 2); total (n = 481 – 681 persons)

The visual routes, trade patterns and migration routes were drawn on ArcGIS and ArcMap using the available dataset and the details from pGIS, and the base map routes for trade and migration. Digitized group presentations standardized by consensus were overlaid with the topographic maps to ascertain the viability of trekking in the terrain with special focus on existence of steep ridges, cliff or geological fault lines that may impede movement. Finally, county-level camel seroprevalence to MERS-CoV were obtained (Table 2) to finalize risk maps.

Table 2: Seroprevalence of MERS-CoV in dromedary camels in selected counties of Kenya

County	Production system	Camel density (per Km Square)	Seroprevalence	Source
Laikipia	Ranching (commercial)	1	6.9%	(Corman et al. 2014)
	Nomadic pastoralism		46.95 %	(Deem et al. 2015)
Isiolo	Nomadic pastoralism	2-3	16.7 %	(Corman et al. 2014)
	Peri-urban camel production system (PUCPS)		Not done	-
Turkana	Nomadic pastoralism	2-3	9.0 %	(Corman et al. 2014)
Wajir	Nomadic pastoralism	4-7	59.0 %	(Corman et al. 2014)
Marsabit	Nomadic pastoralism	2-3	72.1%	(Corman et al. 2014)
Mandera	Nomadic pastoralism	8-18	56.2%	(Corman et al. 2014)
Nakuru (Naivasha)	Commercial ranch	<1	12.0%	This study

Results

Camel production in Kenya

Based on the available dataset, camel production is an integral part of the Kenya pastoral farming system and is mostly resident in the northern rangelands and arid and semi-arid (ASAL) counties (Figure 1). However, this trend appears to be changing and currently the central (Laikipia, Baringo and West Pokot) and southern (Kajiado and Taita Taveta) rangelands counties are slowly gaining prominence as key camel producing areas (Figure 1 and Table 1). Based on field interviews, camels are reared mainly for subsistence and as dairy animals for commercial milk production but less for meat production in Kenya.

Two management systems used for camel production in Kenya are the traditional pastoralism (Nomadic and transhumance Pastoralism) and the semi-sedentary system (Peri urban market oriented systems, ranching and off-farm camel management for ecotourism, camel safaris and camel racing) with very limited commercial system (Table 1). County-level characteristics and production systems are available in Supplementary material 1b.

The traditional pastoralism is highly extensive and is the most prevalent system constituting over 98% of the total camel population while the semi-intensive system constitute approximately 1%, and mainly from Isiolo, Laikipia and Kajiado. Using the 2014 livestock census, the camel population in Kenya was ≈ 2.9 million heads (FAOSTAT, 2015). An estimated absolute population growth for the year 2009 until 2014 was 3.36% with a mean annual growth of 0.56%. The year on year annual increase was ≈ 2.0 %, 2.0 %, -7.3 %, 1.2 %, 1.3 %, and 4.2% for 2010, 2011, 2012, 2013, 2014 and 2015 respectively. In 2012, there was a severe depression (> 7%) in the growth rate for camel production in Kenya and the highest increase was projected for 2015.

In terms of camel heads (absolute numbers) and population densities, Kenya has approximately 3.1 million camels with Turkana (27.3%), Wajir (23.4%), Mandera (19.5%) and Garissa (16.0%) having the highest population in that order, while Mandera remains the camel densest community with approximately 8-17 camels per square kilometer (Figure 1). In addition, camel densities continue to reduce as one transit from the extreme north east to the south west part of Kenya (Figure 1).

Livestock movement, trade and market linkages

Marketing of livestock (cattle, camels, sheep and goats) in Isiolo, Laikipia and Marsabit is representative of what transpires in other Kenyan pastoralist communities. The in and out-flows of people and livestock to the markets, and the volumes vary significantly across the different categories of markets and also the months of the year (Tables 3,4,5). The closer a market is to a terminal (final destination of the camel), the higher the level and volumes of traders, diversity of actors and animal numbers (Tables 3,4,5). Additionally, livestock from secondary markets are transported to many destinations and have linkages with long-distant markets. Using the MPT, it was inferred that the risk of intra- and interspecies

transmission of disease is considered higher in secondary (terminal) markets compared with the primary (bush) markets (Tables 3). More cattle, sheep and goats were traded through the markets compared with camels. Sale of donkeys was sparingly done and was reported only in Isiolo livestock auction yard. Seasonal variations in sales were influenced by annual migration of livestock to locations away from the markets in search of forage and water (Figure 2a & b); during such movements, there fewer livestock are available for sale in the markets. Similarly, fewer animals were presented to the markets during the wet months of late March up until early June, and in the months of October to December. During these months, camels and cows are at their peaks in terms of production and productivity, and lush pastures are abundant, with resultant increase volume of milk for the pastoral household and the need to sell off animals to purchase food stuff is not warranted. Interviews with the traders suggested that the price of livestock skyrocketed during the low offtake period but this increased prices of livestock does not seem to trigger increased supply of animals by the pastoralists.

Table 3. Comparison of trade volume, livestock sources and origin-destination between primary and secondary markets in Marsabit, Kenya

		Merille secondary market	Illaut Primary market
Numbers traded in single market day	Camels	100	10
	Cattle	200	10
	Sheep and goats	1000	300
	Donkeys	0	7
Source		Many - Illaut market, Korr market, bush markets in Laisamis sub county , Bargoi in Samburu and Producers in Laisamis Sub county	Few - Bush markets in Kargi / South Horr and Korr/ Ngurunit wards
Destination		Far and wide -Moyale(camels) , Isiolo, Meru and Nairobi(sheep and goats)	Limited destination- Merille market , Kargi
Actors involved		Many- highly accessible (Isiolo - Marsabit road)	Few- poor accessibility by road.

Source: Marsabit Livestock office and Merille market LMA

Table 4. Annual mean volume of livestock traded in selected secondary markets in Laikipia, Marsabit and Isiolo Counties, Kenya

| Market volumes							
County		Markets	Seasons	Camels	Cattle	Sheep & goats	Donkeys
Laikipia	Secondary	Rumuruti Market	Low	0	250	1000	0
			Normal	0	400	1500	0
			High	0	750	2500	0
		Doldol Market	Low	5	40	150	0
			Normal	10	60	300	0
			High	15	100	600	0
Marsabit		Merile	Low	20	80	600	0
			Normal	50	120	800	0
			High	80	200	1200	0
		Moyale	Low	20	50	200	0
			Normal	50	50	200	0
			High	60	70	800	0
Isiolo	Secondary	Isiolo Auction yard	Low	0	200	200	20
			Normal	0	300	500	12
			High	0	800	2000	12
		Duse	Low	2	0	70	0
			Normal	7	0	150	0
			High	15	0	500	0

Source: County livestock movement report.

Table 5. Seasonal variations in volume of livestock traded in the six profiled markets

| Seasonal Variation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Peak sales (camels -30, cattle-320, sheep & goats-1200)						⟵═══════⟶						
Normal offtake (Camels- 20, cattle - 155, sheep & goats - 575)	⟵══⟶					⟵══⟶						
Low offtake (camels-7, cattle- 100, sheep & goats - 370)			⟵═══════⟶							⟵═══════⟶		

Source: County livestock markets reports and key informant interviews

LRA 2010 Major Migration Patterns
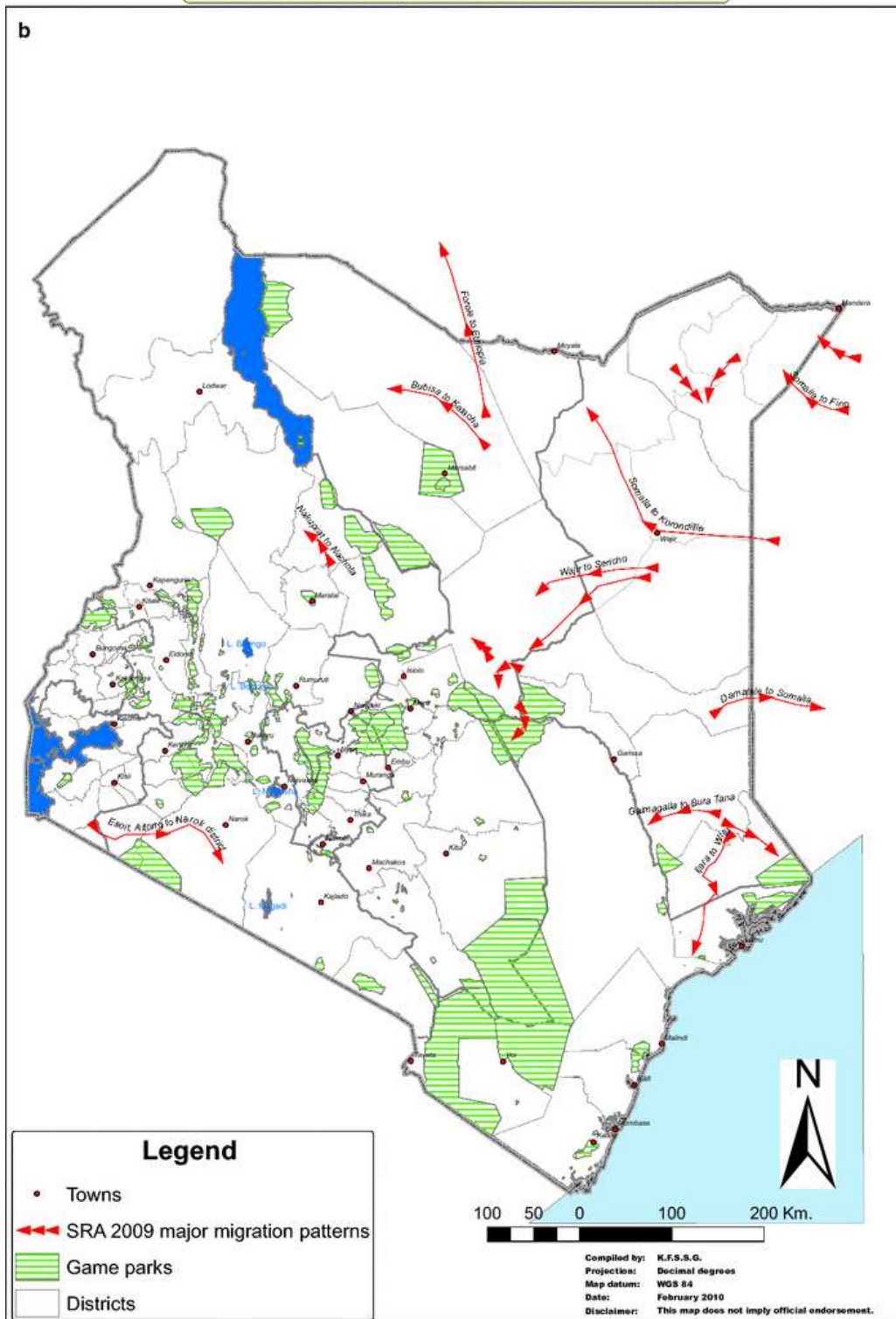
Figure 2. Impact assessment and major migration patterns of livestock associated with **a** long rain assessment (LRA–April to October), and **b** short rain assessment (SRA–November to March). The long and short rains influenced the patterns of movement of animal annually. Vegetations improve in-country during long rains, and these significantly influence in-migration. Conversely, dry seasons and period of short rains are characterized by sparse vegetations which cause out-migration of camels and other ruminant livestock.
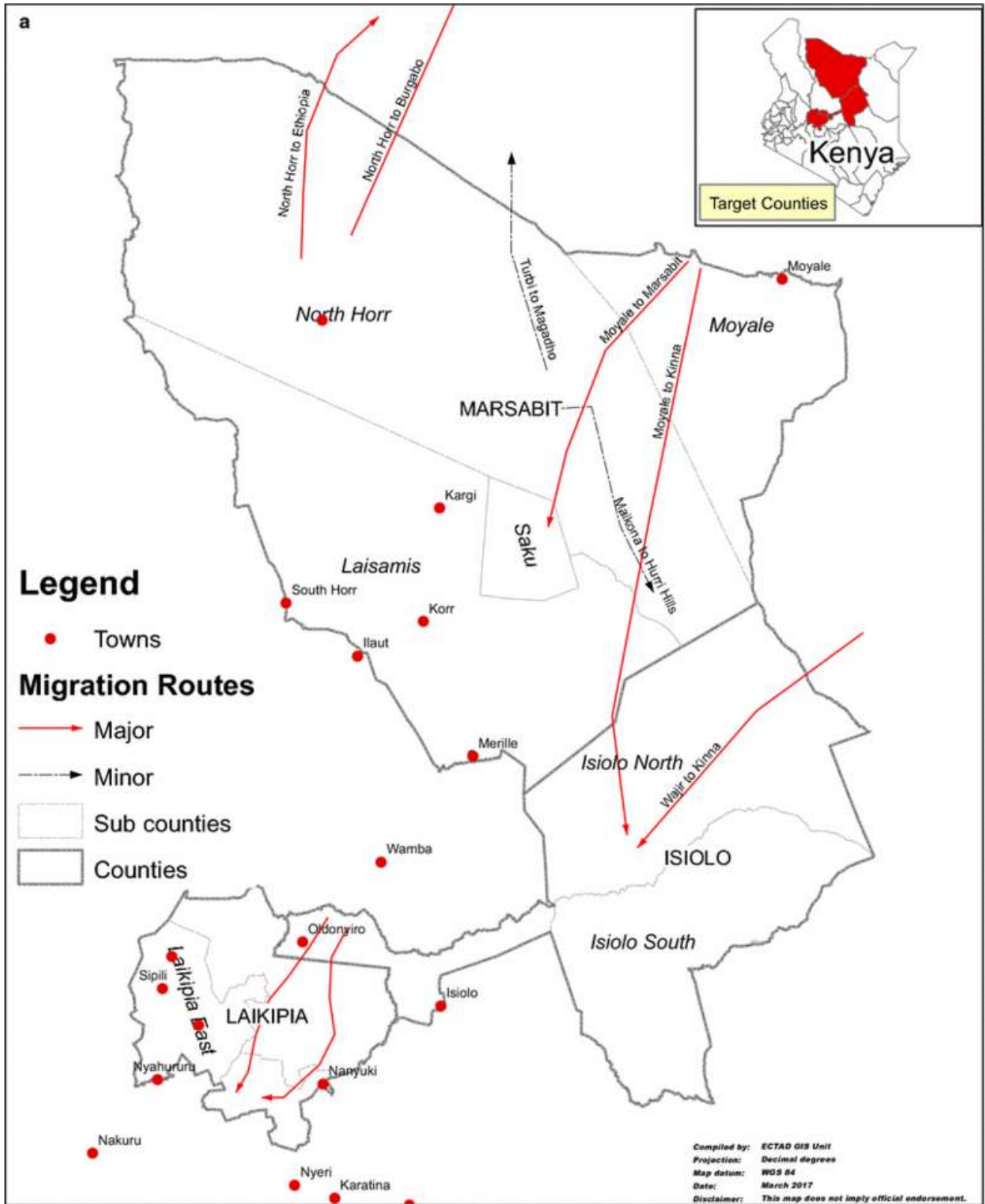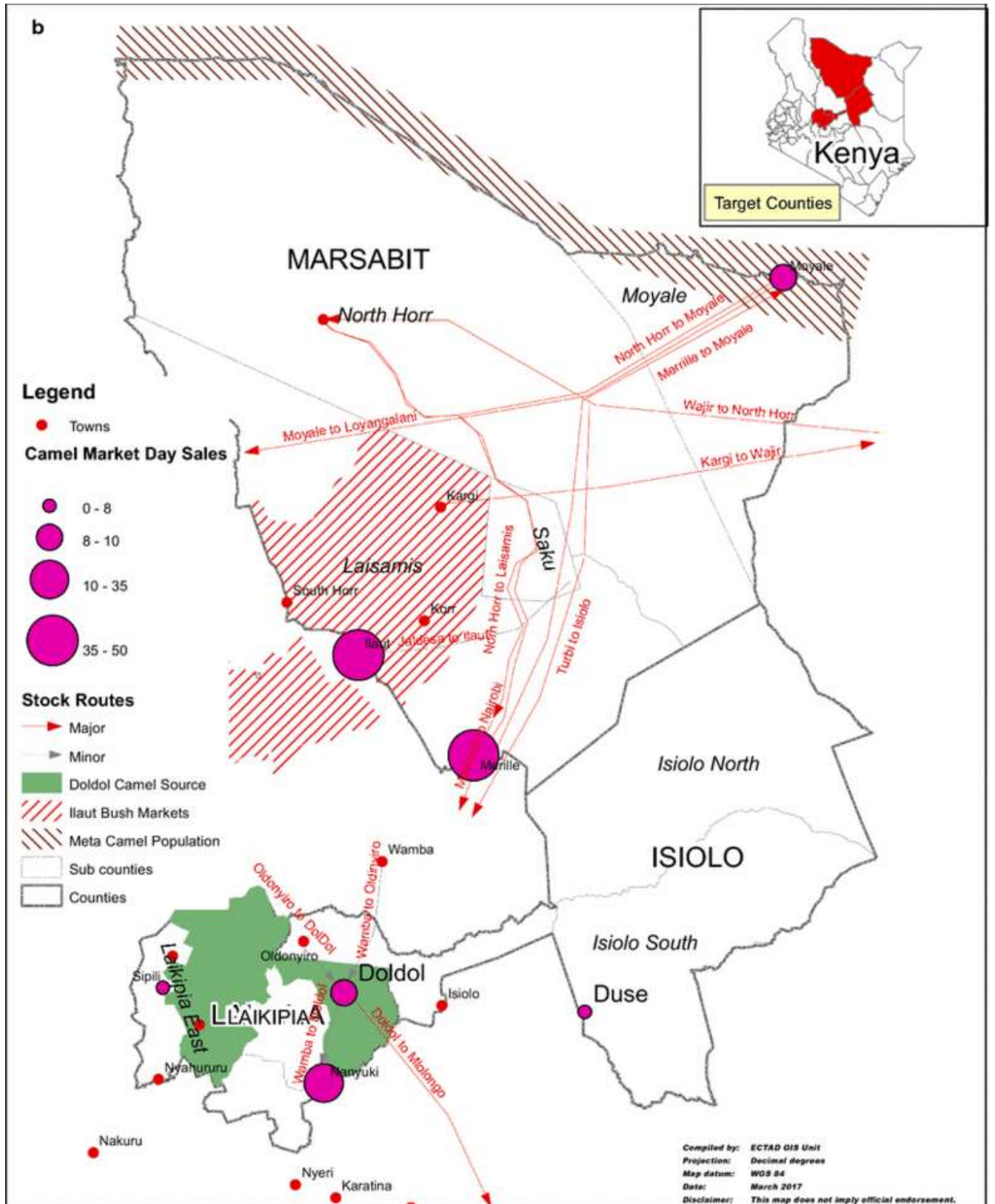
Figure 3. a Camel migration routes and **b** Market volumes and stock routes in some major camel-producing counties (Laikipia, Marsabit and Isiolo), Kenya.

Camel-specific sales, marketing network and migration routes

Camels were not traded in two (2) of the six (6) profiled markets –Rumuruti in Laikipia and Auction yard in Isiolo (Table 3b). Furthermore, traded volumes for camels (n = 5- 80) were significantly low compared with those of sheep, goats and cattle in all the surveyed markets.

Using the details of the pGIS conducted in Isiolo and Marsabit, the following trade routes have been identified: (1) Wajir- Isiolo- Meru- Mwingi – Athi River (Major route), (2) Merille- Moyale – Ethiopia – Djibouti- Egypt- Middle East (Major route), (3) Merille – Isiolo-Meru- Mwingi – Athi River- (Major route), (4) Wajir- North Horr (Maikoma ward) – Barter trade -heifers and return with bulls to Wajir (Minor route) (Figure 3).

Camels migrate from most counties to Kinna area of Isiolo, a dry season grazing area for cattle, sheep and goats where pastoralists congregate with their livestock herds for dry season grazing. Furthermore, camel stock route from Moyale to Marsabit involves barter trade in which mature bull camels -destined for the Djibouti holding ground for onward sale to the Middle East markets- are exchanged for female calves that are later sold in the Marsabit region (Figure 3). Similar scenario was noted on the Wajir-North Horr stock route in which traders brought female calves from Wajir to exchange with mature bulls in North Horr which are then trekked to Wajir County and sold to neighboring Somalia

Camel slaughter in selected counties, Kenya

Although camel meat is not very popular meat among Kenyans, the trade in camel meat in Nanyuki and Isiolo towns is primarily a preserve of Somali traders. Seven such butcheries have been identified: three (3) in Nanyuki and four (4) in Isiolo. Few other such facilities may exist elsewhere within the country. Camels for slaughter are sourced directly from ranches/pastoral herds and also from the livestock markets of Doldol and Merille. Slaughtering of camels was carried out in Nanyuki and Isiolo town municipality slaughter slabs (Supplementary material 1c). Distinct slaughters slabs are used for camels, cattle, sheep and goats in each town but all within the same precincts. Stunning guns were used by the operators to

immobilize the animals before slaughtering as required under the animals welfare regulations. However, the level of hygiene in the investigated slaughter slabs and biosecurity were poor.

Seroprevalence of MERS-CoV in Kenya camel herds

Dromedary camels from Kenya have presented with antibodies against MERS-CoV and the virus has been in circulation for over 20 years based on serologic evidence (Jores 2015, Deem et al. 2015, Müller et al. 2014). Specifically, the following levels of seroprevalence MERS-CoV antibodies have been reported: Marsabit (72.1%), Wajir (59.0%), Mandera (56.2%), Laikipia (6.9-47.0%), Isiolo (16.7%), Nakuru (12.0%) and Turkana (9.0%). Seroprevalence was positively correlated with camel densities per counties with a correlation value of 0.55 ($P = 0.20$), frequency of animal and herd contacts but negatively correlated with absolute camel population per county (Correlation value = -0.06, $P = 0.92$).

Discussion

Risk mapping and prioritization of MERS-CoV hotspots

Risk analysis and decision support to prioritize potential hotspots for MERS-CoV amplification and transmission should be based on empirical evidence. In this work, we have conducted camel production system characterization, market–related variables and practices as basis for determining MERS-CoV hotspots and risk nodes. These maps can serve as bases for future decision on risk-based disease surveillance in camels for Kenya and in the sub-region. Camel value chain should be investigated further to identify, qualify and quantify risks, critical control and intervention points (risky nodes), socio-anthropogenic risky behaviors and practices that facilitate the propagation of pathogens.

Whereas we have identified and ranked counties with high camel population density for prioritized surveillance, and as potential hotspots, socio-anthropogenic features, challenges of security, unique production systems, trade dynamics and unfavourable geographic features that discourage animal production and movements in certain areas may influence a re-prioritization. Based on these identified challenges, Mandera, Wajir, Garissa,, Samburu,   and Baringo counties, although were ranked among

the high density camel counties, were left out of the study. . Such locations can only be investigated using specialized security-backed animal disease surveillance programme. Marsabit and Turkana counties were ranked among the first 5 counties with high camel densities and had minimal security challenges, and were therefore selected for risk-based camel disease surveillance areas alongside Isiolo, Laikipia, and Nakuru counties with moderate camel densities.

Value chain nodes

Market-based surveillance should target secondary markets which are prone to higher risks compared with the primary markets. In this study Merille (operates every Tuesday with trade volumes of approximately 50 camels), Duse (Tuesday, 7 camels) and Moyale (Wednesday, 50 camels) were identified for such evaluation. Virological and serological surveillance should also focus on slaughter slabs in Isiolo and Nanyuki towns with average slaughter capacities of 48 and nine (9) camels per week because slaughter slab workers may be predisposed to camel-related zoonoses. Consideration for surveillance along the migration routes should focus on spatial-temporal convergence points including: (1) Losai thorny bushland in Laisamis Ward of Laisamis sub-county which is located southwest and adjacent to the Marsabit National Reserve as well as (2) Kinna Ward in Garbatulla sub county in Isiolo county which receives highest rainfall, and is near to Nyambene hills in Meru. For trade routes, focused surveillance should target identified routes including: (1) Wajir - Isiolo - Meru - Mwingi – Athi River, (2) Merille - Moyale – Ethiopia – Djibouti – Egypt - Middle East, (3) Merille – Isiolo – Meru - Mwingi – Athi River, (4) Wajir - North Horr (Maikoma ward) – Barter trade - heifers and return with bulls to Wajir. Peri-urban camel production systems (PUCPS) are beginning to gain prominence especially around Isiolo town, and they comprise of traceable milking herds (usually 10-50 camels in size), which are grazed within the proximity (10-30Km) of the town. The camel-human interactions facilitated by this system as well as the potential zoonoses associated with milk and other products from these herds necessitated a special surveillance system. However, herd recruitment for programmed surveillance is complicated

because the majority of such herds are owned by several (3-5) pastoralists who may have different programmes..

The northern and eastern rangelands are traditional camel producing areas in Kenya, however, camel production has emerged as an important activity in central and southern counties: West Pokot, Kajiado, Tana River, Elgeyo Marakwet and Laikipia due to influence of climate change, and conflicts associated with animal movement, cattle raiding and diseases; and as a strategy for livelihood diversification because camels thrive where cattle fail in unfavourable conditions (Guliye et al. 2007). Specifically, pastoralist preference and shift from cattle to camels and small ruminants has gained prominence in order to adapt to drastic changes in vegetation ecology. Whereas small ruminants are mainly browsers and utilize significantly less feed resource compared with cattle and will thrive better in sparse grassland, camels can live in hot arid environment and avoid hyperthermia, cope with drought and maintain body conditions, survive for a much longer period and travel for 5-7 days without food and water without impairment to their physiology (Ouajd & Kamel, 2009).

The Counties under review (n = 14) account for approximately 90% of the national camel herd and are the most important camel producing areas, consists of 2.4 million households and representing 26% (13 million individuals) of the Kenyan population (KNBS 2017). A significant proportion of this human population are at risk of losing livelihoods (trade bans that may be associated with ban on camels and camel products in the event of MERS-CoV), food security (milk and associated products) and infection with diseases like MERS-CoV and camel-associated human brucellosis in an uncontrolled camel farming sector. It becomes imperative that the county and national governments jointly develop industry support programmes and implement animal disease control in these counties.

As camel production gain more prominence in Kenya's central and southern rangelands, better management methods are advocated. Production function (milk and milk-products) is relevant to the camel value chain particularly in sub-Saharan Africa (Noor 2013). The estimated tonnage and worth of total camel meat produced in 2013 in Kenya were put at between 700 – 10,000 tonnes and approximately

Ksh 1 billion (≈ US$10 million) respectively, and between 200 – 350 million litres of camel milk was produced annually at a net worth of over Ksh 2 billion (≈ US$20 million) (Anon, 2005; ZED, 2015). The reproductive efficiency of camels under traditional pastoral conditions is low with short breeding season, late attainment of puberty and the long gestation period of approximately 13 months; over 90% of the Kenyan camel herds currently operate under this system and will need improvement (Kaufman and Binder, 2002; Skidmore, 2003). Potential export market can be explored in addition to local economy and a shift to more resident herding system (ranching) and commercialization can tremendously increase camel values and reduce the limitations associated with the traditional pastoralism (Kaufman and Binder, 2002).

Traditional pastoralism requires large expanse of land, and it comes with inefficient resource utilization, prone to conflicts, have potential to disseminate disease over large areas and makes camel population census difficult. It however has the benefit of reduced disease intensification per unit space and limited animal-human contacts with implication for reduced zoonoses.

In the Arabian Peninsula, where high number of human cases of MERS-CoV has been recorded, camel production is highly intensive and human-animal (camel) contacts appear more intense (Nowot & Kolodziejek, 2014; Omrani et al., 2015; Sabir et al., 2016). To-date, Kenya has recorded zero human cases of MERS-CoV. This observation could be due to limited animal-human contacts, lack of a MERS-CoV surveillance system, pathogen biology or the virus is absent. Currently, camels have been linked with the emergence of and zoonotic transmission of MERS-CoV (Dudas and Rambaut, 2016) and countries in the HOA contribute significantly to the volumes of camels exported to North Africa and the Middle East, it becomes mandatory to implement risk-based surveillance in export markets such as Merille, Doldol, Moyale and Duse. Surveillance may include value chain nodal analysis, repeat sampling as well as socio-anthropological studies of actors and traders that may promote the emergence, circulation, amplification and intensification of MERS-CoV.

Although north-eastern counties were important camel areas, whether transboundary movement through Mandera, Wajir, Marsabit and other counties in north-east Kenya, or camel residency influence the

absolute population figures and the densities were not investigated in this study. Perhaps a national camel population study conducted during periods when vegetation index is favourable and animal movement is limited may present with a different outcome. National camel identification project that may assist with animal traceability (in-migration, out-migration and within-country movement) is necessary. Because there have been direct correlation between animal population densities and animal disease (Olive et al. 2016; Corman et al. 2014), targeted surveillance should be prioritized in these camel-dense counties. In this work, counties with high seroprevalence (Marsabit, Wajir and Mandera) were primary high transit areas for camel movements and were positively correlated with camel densities, frequent animal and herd contacts. Jores (2015) argued that antibody levels of nomadic camels are significantly higher than those from ranches and that herds in north eastern parts showed increased seropositivity than camels in the north western and our finding is in agreement with this assertion. Muller et. al (2014) have earlier reported that Kenya receives many camels from Somalia and Sudan where seroprevalence values were as high as over 90%. These herds enter Kenya through Mandera, Wajir and Garissa thereby increasing animal-to-animal contacts in cross-border camel meta-populations.

In addition to animal population density, virus transmission might also be influenced by camel movement, socio-anthropological behavior of pastoralists, trade networks, and slaughter practices. We observed a poor level of hygiene in the investigated slaughter slabs, weak implementation of biosecurity and extensive trade networks facilitated limited but sometimes intense contacts between camels from the different counties and those from Sudan, Ethiopia and Somalia especially during droughts, when limited water resources are available for sharing within the affected ASALs. The animal movement is an integral component of livestock marketing, and these movements are potentially risky for long-distance infectious diseases transmission across substantial geographic areas.

Although the price of livestock skyrocketed during the low offtake period, it did not influence supply of animals by the pastoralists. Economics principle suggests that there is an inverse relationship between the supply and prices of goods and services if demand remains unchanged. It was expected that with the

relatively high price and relative increase in demand, the supply chain should be triggered to meet the challenges. This position is true for most of the agricultural production enterprises, however, it will appear that pastoralists do not respond to market prices by increasing or decreasing production rather, and the role of livestock to them goes beyond the ordinary economic principles. Most farmers rather hold their herds/flocks more like an investment portfolio/bank and only draw from it as needs arise (Barrett et al. 2006).

Camel trade and migration routes

Based on pGIS, four important trade routes have been identified above. It is pertinent to note that these trade routes traverse parts of the country's ASAL terrains and cross one another in the course of animal movement mainly influenced by drought. At such periods, domestic and wild animals concentrate around watering points, river course and feed resources with increased level of interactions between domestic and wild animals. Such intense interaction may introduce and amplify disease pathogens and increase the likelihood of disease outbreaks. Such outbreaks are recorded periodically in Kinna, Cherab and Garbatulla areas of Isiolo, a dry season grazing area for cattle, sheep and goats (Wasonga et al., 2016). Furthermore, in the situation of acute food shortage for camels during drier periods, and as part of trade practices, some of the stock routes do trade by barter e.g. (1) Moyale to Marsabit barters mature bull cdestined for the Djibouti and ultimately the Middle East markets for female calves to be sold in the Marsabit region; (2) Wajir - North Horr barters female calves from Wajir for mature bulls in North Horr which are then trekked to Wajir County and sold to neighboring Somalia (Figure 3). The implications of these barters in the epidemiology of MERS-CoV and other camel diseases cannot be underestimated.

Although camel meat is not popular in Kenya, the trade in camel meat in Nanyuki and Isiolo towns remains a preserve of Somali traders. Seven such butcheries have been identified and (Supplementary material 1c). Hygiene and biosecurity levels in these niche markets should improve and pre-slaughter inspections should be carried out on camels meant for slaughter.

The sero-evaluation for antibodies to MERS-CoV antibodies in dromedary camels from Kenya presented with location specific results. Previous serological works have suggested that Kenya may have had the MERS-Co virus in circulation (Jores 2015, Deem et al. 2015, Müller et al. 2014). Our conclusion is in agreement with these assertions and we confirmed that camel population density per county, volume of camel movement through counties and intense animal - animal contacts are associated with high seropositivity. Jores (2015) had earlier argued that herds in north eastern parts showed increased sero-positivity than camels in the north western parts of Kenya. East-African sub-regional herds enter Kenya through Mandera, Wajir and Garissa counties thereby increasing animal-to-animal contacts and this may be responsible for the high level of seropositivity in camels from this axis.

We have demonstrated that Kenyan camels are predisposed to coronaviruses including MERS-CoV but no evidence suggests shedding of the virus based on the serologic result in this study. We have also determined potential hotspots based on empirical facts, system and trade characterization. Outputs from this study should guide careful selection of sampling and surveillance sites, high risk locations, critical areas for interventions and policy development to support camel production and trade in Kenya. It is hoped that virological examination of Kenya's camel will be conducted in due course to add to the understanding of epidemiology of MERS-CoV globally.

Acknowledgement

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Supplementary material 1a. Market profiling tool used for the camel value chain Kenya, 2016

Market profiling tool 2016.					
Name of the market.		Classification of the market..			
Variable	Description	information to be collected			
1. Location of market	geographical location	1.1 ward			
		1.2 Sub county			
		1.3 County			
		1.4 National			
		1.4 GPS			
2. Operation shedule		2.1.Market days in a week			
		2.2. Does it open in all weeks			
			No.	Average price	
3. Livestock species traded during low seasons	camels, cattle, shoats, donkeys, monthly	3.1 camels #			
		3.2 cattle #			
		3.3 shoats #			
		3.4 donkeys #			
4. Livestock species traded during normal seasons	camels, cattle, shoats, donkeys, monthly	4.1 camels #			
		4.2 cattle #			
		4.3 shoats #			
		4.4 donkeys #			
5. Livestock species traded during high season	camels, cattle, shoats, donkeys, monthly	5.1 camels #			
		5.2 cattle #			
		5.3 shoats #			
		5.4 donkeys #			
6. seasonal variation in demand	specific months	6.1 high season months			
		6.2 normal season months			
		6.3 low season months			
7. Sources of camels brought to market	Supply from other markets within and outside the county. Supply may be directly from producers (give name of ward/ village)	Name main markets and main rural admin areas supplying the market directly	category of market, ward or village	% sourced	main mode of transport
		7.1.			
		7.-----------			
8. Destination of camels bought from market	Destinations - other markets, within and outside county, towns for slaughter, to ranches/l herds breeding	Name of market, towns and rural admin areas that ate the main destination for pruchased animals	category of market, ,town, ward or village	% sourced	main mode of transport
		8.1.			
		8.---------			
9. Sources of cattle brought to market	Supply from other markets within and outside the county. Supply may be directly from producers (give name of ward/ village)	Name main markets and main rural admin areas supplying the market directly	category of market, ward or village	% sourced	main mode of transport
		9.1.			
		9.---------			
10. Destination markets for cattle bought from market	Destinations - other markets, within and outside county, towns for slaughter, to ranches/l herds for breeding	Name of market, towns and rural admin areas that ate the main destination for pruchased animals	category of market, town, ward or village	% sourced	main mode of transport
		10.1.			
		10.---------			
11. Sources of shoats brought to market	Supply from other markets within and outside the county. Supply may be directly from producers (give name of ward/ village)	Name main markets and main rural admin areas supplying the market directly	category of market, ward or village	% sourced	main mode of transport
		11.1.			
		11.-----------.			
12. destination markets for shoats bought from market	Destinations - other markets, within and outside county, towns for slaughter, to ranches/l herds for breeding	Name of market, towns and rural admin areas that ate the main destination for pruchased animals	category of market, town, ward or village	% sourced	main mode of transport
		12.1.			
		12.-----------			
13. Under reporting	% of animals that are brought to market and are not traded and therefore not recorded	cattle	camels	shoats	
14.Disease monitoring /control		services offered	adequate	not adequate	
		screening			
		quarantine			
		treatment of sick animals			
		animal walfare enforcement			
15. Chargable fees	cess	permits	trekking	trucking	loading
shoats					
cattle					
camels					
donkeys					
16. General observations	Access to the market				
	Market integration with other commodities				
	Market integration with other commodities				

Supplementary material 1b. Characteristics of prioritized counties for MERS-CoV disease surveillance and behavioral studies

County	Key consideration factors	Remark
Wajir	• High camel density (4-7 camels per Km^2) • Nomadic pastoralism-increased interaction between herds • Border county -increased animal-to-animal contact in cross-border dromedary camel meta-populations	Highly prioritized but left out due to current security concerns in the County
Mandera	• High camel density (8-17 camels per Km^2) • Nomadic pastoralism- increased interaction between herds • Border county -increased animal-to-animal contact in cross-border dromedary camel meta-populations	
Isiolo	• Camel density of 2-3 camels per Km^2) • Has both nomadic pastoralism and Urban and Peri Urban camel production system- increase animal to animal and human to animal contacts • Migration into the county - increased interaction of camel herds from other counties.	These were selected particularly due to intra/inter herds interactions, cross border camel meta-populations and camel – wildlife interactions.
Marsabit	• Camel density (2-3 camels per Km^2) • Nomadic pastoralism- interaction between herds • Border county -increased animal-to-animal contact in cross-border dromedary camel meta-populations • Cross border camel trade at Moyale- camels heading to Egypt and Middle east	
Turkana	• Camel density (2-3 camels per Km^2) • Nomadic pastoralism-increased interaction between herds • Border county -increased animal-to-animal contact in cross-border dromedary camel meta-populations	
Laikipia	• Low camel density (1 camel per Km^2) • Nomadic pastoralism -increased interaction between herds • Ranching and wildlife conservancy- interaction between wildlife and camels	
Nakuru (Naivasha)	• Commercial ranch in Naivasha – has resident camel herd that is appropriate for longitudinal surveillance despite having minimal inter herd contacts.	purposively targeted for longitudinal surveillance

Supplementary material 1c. Analysis of two main camel slaughter slabs in Key camel production counties

	Nanyuki County	Isiolo County
Name of Slaughter slab	Nanyuki town camel slaughter slab	Isiolo town camel slaughter slab
Ownership	Public	Public
Location (GPS)		
Operational days	Monday, Wednesday and Friday	Monday- Saturday
Number of Camels slaughtered per week	9	48
Sources of camels	Ranches, Doldol market, Direct from pastoral herds in Laikipia North.	Merille and Duse markets, direct from pastoral herds in Garbatulla, Laisamis
Destination of Carcasses	Nanyuki town, South C in Nairobi	Isiolo town, Eastleigh in Nairobi
Status of infrastructure	Roofless slab , poor drainage and disposal of waste within same compound with cattle and small ruminant slabs	Roofless slab, poor drainage and disposal of waste, Adjacent to Cattle slaughter slab.

A camel slaughter slab, low biosecurity and lacking basic infrastructure missing