Risk of foot and mouth disease spread through cattle movements in Uganda

This paper (No. 20102021-00188-EN) has been peer-reviewed, accepted, edited, and corrected by authors. It has not yet been formatted for printing. It will be published in issue **39** (3) of the *Scientific and Technical Review*, in 2021.

I. Mugezi [(1, 2)*], M. Kimaanga [(1)], A. Namwabira [(1)], E. Chevanne [(3)], O. Nekouei [(3, 4)], M. McLaws [(3)], P. Motta [(3)], T. Dulu [(5)] & K. Sumption [(3)]

(1) Department of Animal Health, Ministry of Agriculture, Animal Industries and Fisheries (MAAIF), Plot 14–18 Lugard Avenue, PO Box 513, Entebbe, Uganda

(2) Department of Production, Trade and Tourism Planning, National Planning Authority, Plot 17A Clement Hill Road, PO Box 21434, Kampala, Uganda

(3) The European Commission for the Control of Foot-and-Mouth Disease (EuFMD), Food and Agriculture Organization of the United Nations (FAO), Viale delle Terme di Caracalla, 00153 Rome, Italy

(4) Department of Infectious Diseases and Public Health, City University of Hong Kong, 31 To Yuen Street, Kowloon, Hong Kong

(5) State Department of Livestock, Ministry of Agriculture, Livestock, Fisheries and Irrigation, Cathedral Road, PO Box 30028-00100, Nairobi, Kenya

*Corresponding author: nythisrael@live.com

Summary

Foot and mouth disease (FMD) is endemic in Uganda, where livestock movements through porous borders and beyond play a key role in the spread of transboundary animal diseases. Data from published and unpublished sources were used to conduct a qualitative risk assessment based on the World Organisation for Animal Health framework to assess the risk of foot and mouth disease virus spread in Uganda through pastoral and trade-related cattle movements from the country's southern border districts. A scenario tree was developed as a conceptual framework, and the risk was assessed by considering factors including the cattle population, proportion of vaccinated cattle, number of live cattle legally moved from districts along the Ugandan–Tanzanian border, the production system in the destination districts and the purpose of the movement. Factors associated with higher risk included live cattle movements for pastoral/grazing and breeding purposes, particularly those towards agro-pastoral (AP) areas, which have the potential to lead to outbreaks on several farms in the destination district and other districts countrywide. Prophylactic vaccination should therefore prioritise districts from which movements of large volumes of cattle to other areas originate and the AP destination districts. Specific awareness campaigns should be conducted in destination districts to improve preventative measures and farm biosecurity levels. This study will inform the revision of the risk-based strategic plan, aimed at reducing FMD impacts in Uganda, as the country progresses along the progressive control pathway for FMD.

Keywords

Animal movement – Disease control – Foot and mouth disease – Progressive control pathway – Qualitative risk assessment.

Introduction

Although foot and mouth disease (FMD) is a disease of low mortality (1), its annual global impact in endemic regions has been estimated at between US$ 6.5 and 21 billion (2). It is endemic in East Africa, including Uganda (1). Outbreaks are caused mainly by four viral serotypes: O, A and South African Territories (SAT) 1 and 2 (3, 4). Outbreak investigation records from the Department of Animal Health (DAH) in the Ugandan Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) show that, in 2019, quarantine due to confirmed outbreaks of FMD had been imposed in over 42% of the 132 districts countrywide. Many more outbreaks probably go unreported; in one study 60% of 128 randomly selected farms were found to have seropositive animals (5). This has an impact on the development of beef, which is a priority commodity in Uganda's third National Development Plan (6).

Uganda is engaged in the progressive control pathway for FMD (PCP-FMD), a core tool of the Global FMD Control Strategy of the Food and Agriculture Organization of the United Nations (FAO) and the World Organisation for Animal Health (OIE) (7). The PCP-FMD aims to progressively reduce the impact and circulation of foot and mouth disease virus (FMDV), to allow safer trade of livestock commodities and improve the livelihoods of stakeholders involved in the livestock value chain. The PCP-FMD prioritises interventions to control FMD where the risk is highest, making the best use of the limited resources available in endemic countries (8). Currently, Uganda is in PCP-FMD stage 2, implementing a risk-based strategic plan (RBSP) focused on risk-based control to minimise the impact of FMD. This plan was approved in 2017 by the Chief Veterinary Officer of Uganda and is to be published after a second revision.

Pastoral and trade-related livestock movements play a key role in the spread of FMD in East Africa, where borders are porous and animal movement control is limited (1). The Ugandan (UG)–Tanzanian (TZ) border has frequent livestock movements in both directions for trade, grazing and transhumance (5), due to the proximity of livestock

markets in Uganda and the existence of vast grazing grounds in northern Tanzania (9). This cross-border movement intensifies during the two dry seasons, driven by traditional transhumant practices, trade connections and the search for water sources and better pastures (1). According to the animal movement records from the DAH–MAAIF, more than 43,000 cattle moved from the two Ugandan border districts (Rakai and Isingiro) to 40 other districts countrywide between 2018 and 2019. These movements are believed to pose a substantial risk of spreading FMD and other transboundary animal diseases (TADs).

The objective of this study was to make a qualitative assessment of the risk of introduction of FMD from two districts at the UG–TZ border to other areas of Uganda (Fig. 1) through live cattle movements during dry seasons. The results of this study will be used to revise and update the FMD prevention and control measures applied in Uganda, as described in the RBSP.

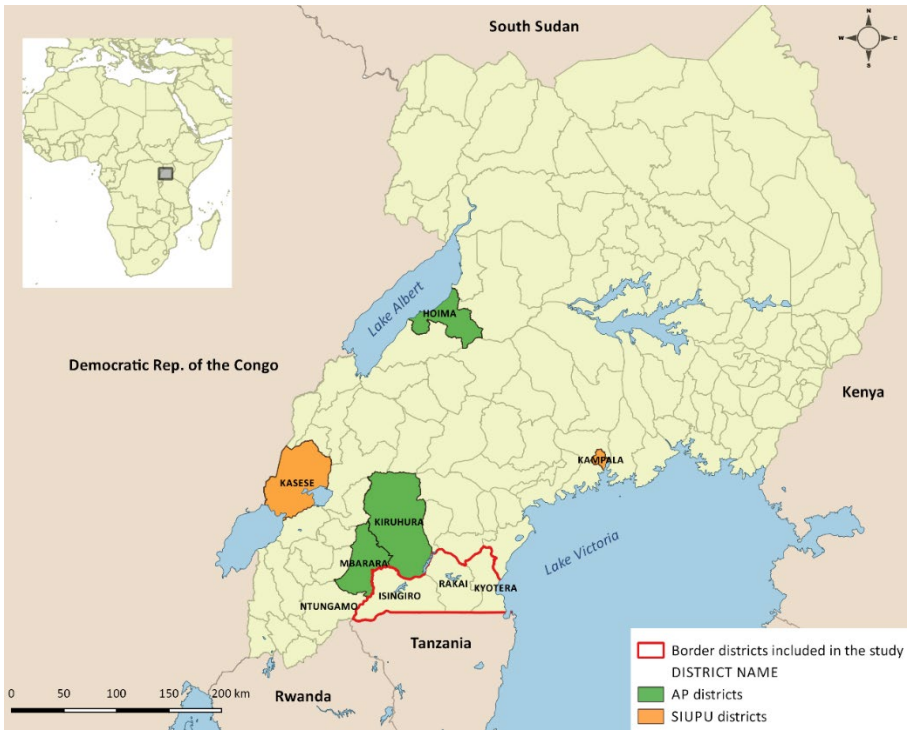

Fig. 1

Ugandan map illustrating the Ugandan districts along the Ugandan–Tanzanian border included in the study

Outlined in red are the border districts included in the study: Isingiro, Rakai and Kyotera (Ntungamo district not considered). Agro-pastoral destination districts are shown in green: Mbarara, Hoima and Kiruhura; semi-intensive, urban–periurban destination districts are shown in orange: Kampala and Kasese. Map generated with QGIS software version 2.18.20, developed by Gary Sherman.

AP: agro-pastoral
SIUPU: semi-intensive, urban–periurban

Methods

The OIE risk assessment framework (10) (Fig. 2) was applied to assess the risk of FMDV spreading from districts along the UG–TZ border to other areas through live cattle movements during the dry seasons. The two dry seasons extend from December to February and from May to August (1) and livestock movements are directed from this border to agro-pastoral (AP) and semi-intensive, urban–periurban (SIUPU) areas of Uganda (Fig. 3).

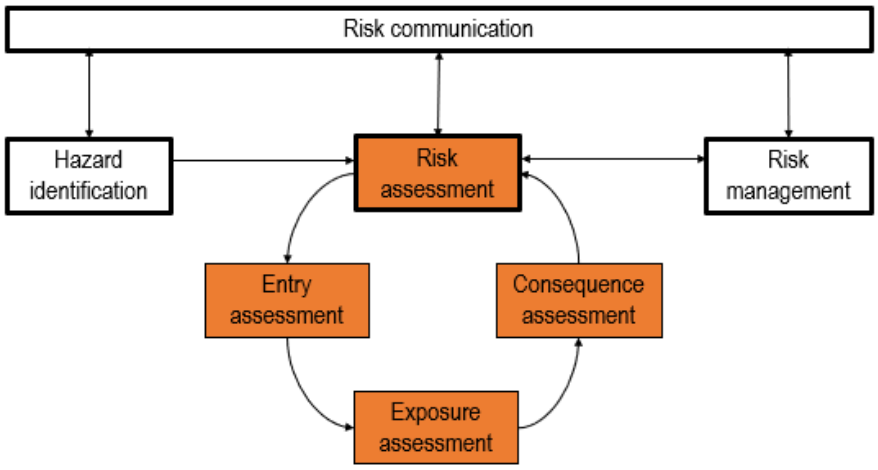

Fig. 2

The four components of risk analysis and the steps of risk assessment (10)

The four components of risk analysis are hazard identification, risk assessment, risk management and risk communication; the main steps of the risk assessment are highlighted in orange.

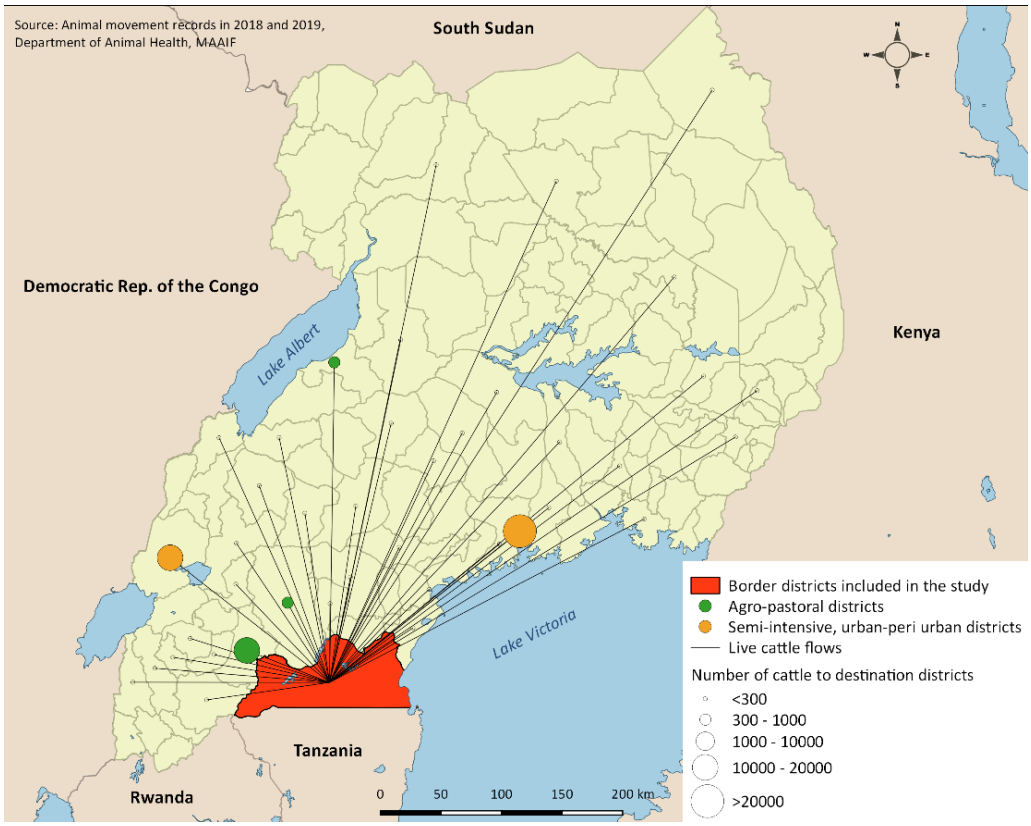

Fig. 3

Cattle movements from the Ugandan districts along the Ugandan–Tanzanian border to other districts in Uganda in 2018 and 2019

Red indicates the border districts included in the study (Ntungamo district not considered). Green indicates the three agro-pastoral destination districts: Hoima, Kiruhura and Mbarara. Orange indicates the two semi-intensive, urban–periurban destination districts: Kampala and Kasese. In 2018 and 2019, 43,739 individual cattle were officially recorded moving from Isingiro and Rakai to 40 distinct destination districts countrywide, and the five destination districts listed above received 88% of the cattle; official cattle movements between Rakai, Isingiro and Kyotera are not displayed.

Data sources: Ugandan districts in 2019, United Nations Office for the Coordination of Humanitarian Affairs (OCHA)'s Humanitarian Data Exchange; Animal movement records in 2018 and 2019, Department of Animal Health, MAAIF. Map generated with QGIS software version 2.18.20, developed by Gary Sherman.

MAAIF: Ministry of Agriculture, Animal Industries and Fisheries

A scenario tree illustrating the entry and exposure risk pathways was developed (Fig. 4). Key biological factors and husbandry practices that may play a role in the introduction and transmission of FMDV in live cattle through trade-related and pastoral animal movements from the border area and study focus were identified in this conceptual model (10).

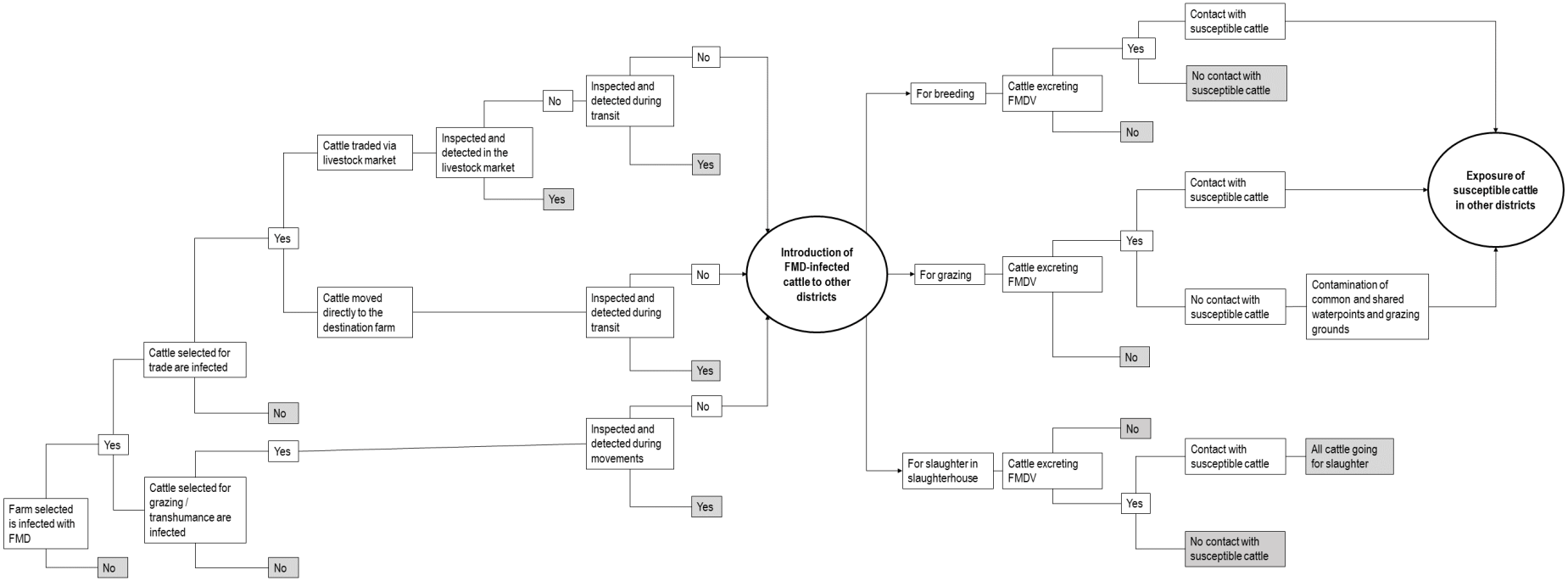

Fig. 4

Conceptual model summarising the entry and exposure risk pathways for foot and mouth disease spread from the Ugandan–Tanzanian border area to agro-pastoral and semi-intensive, urban–periurban areas in Uganda

Grey boxes represent dead-ends for further spread of FMDV

FMD: foot and mouth disease
FMDV: foot and mouth disease virus

The likelihood of the occurrence of each event along the risk pathways was qualitatively assessed using a descriptive scale adapted from Moutou *et al.* (11) (Table I). Assessment of the likelihood of occurrence of each event in the pathway was assessed based on available data, expert opinion and key informant interviews or field observations to arrive at the level of likelihood. The events in the risk pathways are conditional, i.e. each one depends on the preceding to occur. Therefore, the overall likelihood for each pathway was considered equivalent to the minimum likelihood of the constituent events. A level of uncertainty was assigned to each estimated likelihood using a three-category scale adapted from Fournié *et al.* (12): low (concrete and sufficient data were available), medium (some but not comprehensive data were available) and high (no concrete data were available; based only on field observations and expert opinion).

Table I

Interpretation of likelihood categories used in this risk assessment

Likelihood category	Interpretation
Negligible	The likelihood of the occurrence of the event is sufficiently low to be ignored
Low	The occurrence of the event is a possibility in a few cases
Moderate	The occurrence of the event is moderately possible
High	The occurrence of the event is very probable (more than 50% chance)

In the consequence assessment, the most likely scenario resulting from each risk pathway was identified, and the potential impacts of exposure to infected cattle and FMDV spread in the destination areas were assessed. The results from the different steps in the framework were summarised in the risk estimation.

The data and information used in this risk assessment were primarily obtained from outbreak investigations, scientific publications, official reports, national animal movement records and FMD vaccination and surveillance reports from MAAIF, supplemented by key informant interviews with the District Veterinary Officers (DVOs) in the respective districts.

Characteristics of the study area

The Ugandan districts along the UG–TZ border are Isingiro, Rakai and Ntungamo (Fig. 1). These districts have large cattle populations of approximately 180,000, 279,590 and 279,000, respectively (13). This study focused on the Rakai and Isingiro districts owing to the high cattle population, availability of high-quality data and regular cross-border cattle movements. The majority of the farmers in these districts practise an AP system of production, in which cattle are kept in kraals, bomas or open areas and grazed on private or public pastures, supplemented with crop residues (14). In Isingiro district, the majority of farms are large-scale with full land ownership (1, 15) and thus transhumance is limited. In Rakai district, however, cattle ownership is dominated by small-scale farms with limited land ownership rights; these farmers frequently travel to access distant grazing grounds and undertake limited interventions for disease control (16). Indigenous breeds of cattle are mostly reared, along with some crossbreed cattle (13). Investment in infrastructure and resources for prevention and treatment of animal diseases is limited.

Five districts that received the most cattle from the border districts were selected for the study ('destination districts'). In 2018 and 2019, these destination districts received 88% of the cattle traded from Isingiro and Rakai districts (transhumance movements are not recorded and no estimate is available). The cattle mostly move for slaughter (94% of movements) and to a lesser extent for breeding (6%) (Table II). The AP system as described for the originating districts predominates in Kiruhura, Mbarara and Hoima districts, whereas SIUPU production is more common in Kampala and Kasese districts. In SIUPU areas, farmers keep small herds, mainly dairy

cattle, and generally spend more resources on animal disease control measures. Cattle are confined and provided with fodder, commercial feeds and crop residues (14). The high volume of cattle moved through trade to Kampala and Kasese is due to a high demand for meat, while for Mbarara and Kiruhura it is due to a higher market price for live cattle because these are cattle transit districts (17). For Hoima the volumes traded are high, probably triggered by cross-border trade with the Democratic Republic of Congo (18).

Table II

Cattle population, proportion of cattle vaccinated against foot and mouth disease and cumulative number of live cattle legally moved from two Ugandan districts along the Ugandan–Tanzanian border to the top five destination districts in 2018 and 2019, according to the purpose of cattle movement (breeding or slaughter)

The grey colour shows the livestock population and the vaccination coverage, while the unshaded section shows the purpose of animal movement.

Source: Animal movement records in 2018 and 2019, Department of Animal Health, MAAIF, Vaccination records MAAIF and Uganda Bureau of Statistics.

	Agro-pastoral destination areas			**Semi-intensive, urban–periurban destination areas**		
District name	Hoima	Mbarara	Kiruhura	Kampala	Kasese	
Cattle population	109,998	149,992	342,315	31,614	97,243	
% vaccinated	7.6%	21.3%	4.4%	0.3%	2.1%	
Cattle moved for						**Total**
Breeding	120 (37%)	2,218 (17%)	546 (81%)	136 (1%)	19 (<1%)	**3,039 (6%)**
Slaughter	207 (63%)	10,968 (83%)	128 (19%)	20,990 (99%)	14,539 (>99%)	**46,832 (94%)**
Total	**327**	**13,186**	**674**	**21,126**	**14,558**	**49,871**

MAAIF: Ministry of Agriculture, Animal Industries and Fisheries

Results

Likelihood of farms selected being infected with foot and mouth disease virus

Foot and mouth disease is endemic in the UG–TZ border districts. Between 2015 and 2019, 140 FMD outbreaks were reported in Uganda. Thirteen of these outbreaks were in the UG–TZ border districts and 111 of them occurred during the dry seasons (19). This area was identified as a high-risk area in a sero-survey, suggesting that many more outbreaks could be unreported (5). Outbreaks are more common during the dry seasons as a result of increased movement of livestock, caused by the pressure of limited pasture and transhumance. Therefore, the likelihood of farms being infected with FMD was assessed to be high (Table III).

Table III

The likelihood and uncertainty levels assigned to each step of the assessment of entry of foot and mouth disease virus from the Ugandan districts along the Ugandan–Tanzanian border to other areas of Uganda

Event	Likelihood	Uncertainty
Likelihood of farms being infected with FMDV	High	Medium
Likelihood of cattle selected for trade from the farms being infected with FMDV	High	Medium
Likelihood of cattle selected for grazing/transhumance being infected with FMD	High	Low
Likelihood of FMD-infected cattle being undetected in the livestock markets	High	High
Likelihood of FMD-infected cattle being undetected during transit from livestock markets or farms	High	High
Likelihood of FMD-infected cattle being undetected during movement to grazing grounds	High	High

FMD: foot and mouth disease
FMDV: foot and mouth disease virus

Likelihood of cattle selected from the farms for trade or grazing being infected with foot and mouth disease virus

Indigenous Ankole cattle are the commonly reared breed in the border districts (13). In adult Ankole cattle, FMD typically causes mild lesions that are difficult to recognise and are more likely to go undetected (20). Calves may be severely affected with FMD but are not commonly traded (15). The majority of producers in the border districts sell their cattle at the farm gate; others are sold in informal or formal livestock markets and some directly to slaughterhouses (16). Farm gate sales are characterised by limited veterinary inspection. Therefore, the likelihood of FMD-infected cattle being selected to move from the farm for trade or grazing/transhumance was assessed to be high (Table III).

Likelihood of food and mouth disease infected cattle being undetected during movement to grazing grounds

Movement of cattle under transhumance is not monitored, and there are no officially designated movement routes for grazing animals, making it hard for the animals to be traced (21). The human resource in the Veterinary Services is also not sufficient to detect sick animals during movement. Therefore, the likelihood that FMD-infected cattle are undetected during the movement to grazing grounds was also assessed as high (Table III).

Likelihood of foot and mouth disease infected cattle being undetected in the livestock markets

Public veterinarians are responsible for the inspection and health certification of cattle in livestock markets (22). However, there are insufficient veterinary staff to adequately supervise the weekly livestock markets in the districts included in this study (District production staff profile, MAAIF 2020, unpublished). Furthermore, the livestock markets lack proper infrastructure (fences, crushes, isolation units and loading ramps) to perform adequate clinical examination and prevent the mixing of cattle prior to the examination (e.g. DVOs Rakai and Isingiro, personal communications). This compromises the

coverage of veterinary inspection. Thus, there is a high likelihood that FMD-infected cattle would not be detected at the market (Table III).

Likelihood of foot and mouth disease infected cattle being undetected during transit from livestock markets or farms

Check points for veterinary inspection exist along common stock routes; however, these are not fully operational owing to lack of veterinary resources (23) and infrastructure to support animal movement control, such as quarantine stations, animal holding grounds and stock route enforcement units, as described in the current RBSP for Uganda. Furthermore, some livestock are moved at night when veterinary inspectors are not on duty (e.g. DVOs Rakai and Isingiro, personal communications). When performed, the inspection during transit consists of a physical examination of all cattle in the truck; if FMD is detected, the cattle are returned to the place of origin. In practice, because of bribery, cattle not meeting the movement requirements are returned to the place of origin approximately 85% of the time (e.g. DVO interviews). The likelihood of FMD-infected cattle remaining undetected during transit was also assessed to be high (Table III). Given that all of the steps in the entry assessment were assessed to have high likelihood, the overall likelihood of FMDV release from the border districts to other areas is 'high', with 'medium' uncertainty due to the lack of comprehensive data (Table III).

Exposure assessment

The exposure assessment estimates the likelihood that susceptible cattle in the destination districts will be exposed to FMDV that has entered with the infected cattle originating from the border districts. Upon entering the destination districts, cattle can be kept for breeding purposes, sent directly to grazing grounds or sent to slaughterhouses (Fig. 4). Depending on the production type, cattle intended for breeding may also have contact with other cattle through grazing.

In all pathways, the susceptibility of the animals in the destination districts, level of farm biosecurity and production systems were

important factors. Between 2017 and 2019, vaccinations for FMD were only carried out in response to outbreaks once a year and covered a very small proportion of these populations (Table II). Thus, the majority of cattle are unvaccinated and susceptible to FMDV infection, except for those immune as a result of previous infections with the same serotype.

Likelihood of exposure during breeding

The level of farm biosecurity in Uganda is generally low in both AP and SIUPU destination areas (24); however, as SIUPU areas have lower cattle populations and cattle are confined within individual paddocks or sheds with secure gates on some farms, and in isolation paddocks for newly introduced animals, the level of farm biosecurity is higher in SIUPU compared with AP destination areas (25, 26). The immunity status combined with farm biosecurity measures make the likelihood of exposure of susceptible cattle to FMDV 'high' when live cattle are introduced for breeding purposes to the AP areas and 'moderate' in SIUPU destination areas, with a 'medium' level of uncertainty due to the lack of comprehensive data (Table IV).

Table IV

The likelihood and uncertainty levels assigned to each step of the exposure assessment of foot and mouth disease virus in the agro-pastoral and semi-intensive, urban–periurban destination areas of Uganda

Event	Destination area	Likelihood	Uncertainty
Breeding	AP	High	Medium
	SIUPU	Moderate	Medium
Grazing	AP	High	Medium
	SIUPU	Low	High
Slaughterhouse	AP and SIUPU	Low	Medium

AP: agro-pastoral
SIUPU: semi-intensive, urban–periurban

Likelihood of exposure during grazing

Exposure during grazing can occur through direct contact and indirectly through contaminated shared water points and grazing grounds.

This pathway is primarily relevant in AP areas; in SIUPU destination areas, cattle are mainly introduced for slaughter (Table II) and intensive and zero grazing are the main methods of farming (25), with minimal potential mixing of infected and susceptible cattle. The likelihood of exposure of susceptible cattle to FMDV through this pathway is therefore considered 'low' in SIUPU destination areas, with a 'medium' level of uncertainty due to lack of comprehensive data.

Unfortunately, data on the number of infectious and susceptible cattle that are moved for grazing and transhumance are not available. The pastoral areas face shortages of water and pasture, motivating transhumance and the use of common grazing grounds and communal water points (25). Direct contact between cattle is considered highly likely, and FMDV has been shown to survive in the environment for extended periods; for example, the virus was found to remain viable in cattle faecal slurry and soil for up to 30 days at 20°C (27). Infected cattle can therefore contaminate pastures and water points with virus that is likely to remain viable, resulting in exposure of susceptible cattle, which can become infected by a low dose of FMDV (28). Overall, the likelihood of exposure of the susceptible cattle to FMDV in AP destination areas was estimated to be 'high', with 'medium' level of uncertainty due to incomplete data (Table IV).

Likelihood of exposure in slaughterhouses

Although cattle mix freely in the slaughterhouse upon arrival owing to absence of isolation units and inadequate clinical examination, they spend less than 12 hours there before being slaughtered. Once live cattle reach the slaughterhouses, they are legally not allowed to move to surrounding herds, unless otherwise rejected. Furthermore, the majority of slaughterhouses are in urban centres with no surrounding

cattle herds. The likelihood of exposure for cattle outside the slaughterhouses via this pathway is therefore considered 'low' (Table IV).

Consequence assessment

Farmers in the AP destination districts are pastoralists and the movements of their livestock are dictated by weather (29). Movements during the dry season force them to mix their herds, using common grazing grounds and communal valley dams (25). The animal movement data from MAAIF show that, during 2018 and 2019, cattle from each AP destination district were moved to between 30 and 73 other districts in Uganda (Fig. 5). Given the extensive movement of cattle for both trade and grazing, combined with low levels of biosecurity, the introduction of FMD to the AP destination districts is expected to result in outbreaks of the disease on several farms within these districts and/or in other districts across the country. In contrast, outbreaks of FMD in the SIUPU areas are likely to remain restricted to the originally affected farms owing to the intensive methods of livestock rearing and higher levels of biosecurity (Table V). This is supported by the disease outbreak records in MAAIF, which show that there were no recorded FMD outbreaks in the two destination districts considered SIUPU between 2015 and 2019 while 15 outbreaks were recorded in the three destination districts considered AP.

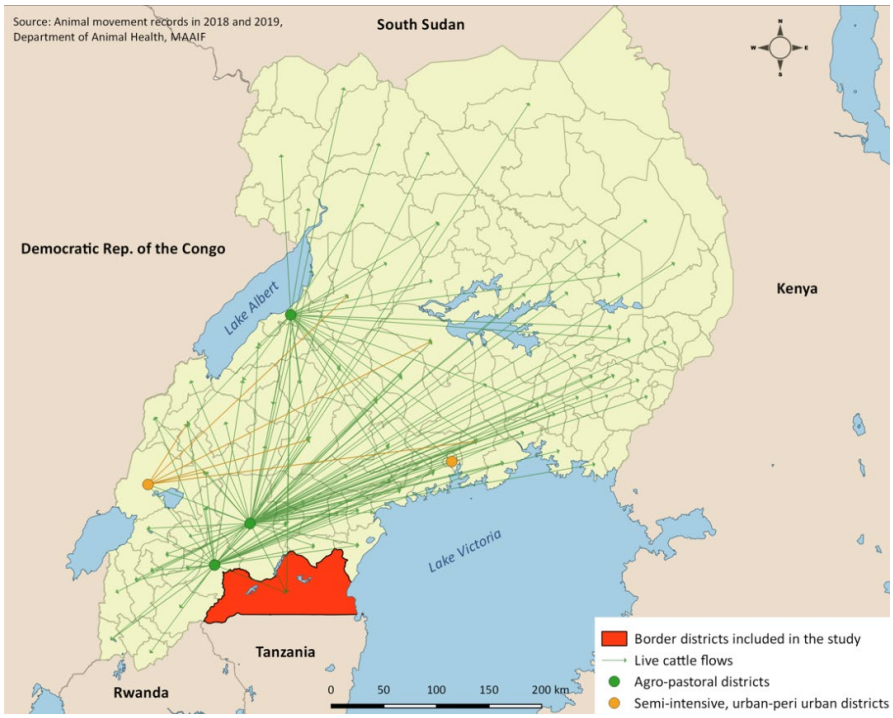

Fig. 5

Cattle movements from the five agro-pastoral and semi-intensive, urban–periurban districts to other districts in Uganda in 2018 and 2019

Red indicates the border districts included in the study (Ntungamo district not considered). Green indicates the three agro-pastoral origin districts: Hoima, Kiruhura and Mbarara. Orange indicates the two semi-intensive, urban–periurban origin districts: Kampala and Kasese. In 2018 and 2019, 75,047 individual cattle were officially recorded moving from the five origin districts listed above to 86 destination districts countrywide (AP districts: Hoima supplied 30 districts, Mbarara 37, Kiruhura 73; SIUPU districts: Kasese supplied 7 districts, data not available for Kampala). Official cattle movements to Isingiro, Rakai and Kyotera were combined in this map.

Data sources: Ugandan districts in 2019, United Nations Office for the Coordination of Humanitarian Affairs (OCHA)'s Humanitarian Data Exchange; Animal movement records in 2018 and 2019, Department of Animal Health, MAAIF. Map generated with QGIS software version 2.18.20, developed by Gary Sherman.

AP: agro-pastoral
MAAIF: Ministry of Agriculture, Animal Industries and Fisheries
SIUPU: semi-intensive, urban–periurban

Table V

Summary of the assessment of the consequence of foot and mouth disease virus spread in agro-pastoral and semi-intensive, urban–periurban destination areas of Uganda

Exposure pathway	Destination area	Most likely outcome scenario	Impact: description of consequences
Breeding	AP	Outbreaks on several farms, or districts countrywide	High: quarantine restrictions, control costs, production losses
	SIUPU	Small outbreak with limited local spread	Low: control costs, production losses
Grazing	AP	Outbreaks on several farms in the whole district	High: quarantine restrictions, control costs, production losses
	SIUPU	Small outbreak with limited local spread	Low: control costs, production losses
Slaughterhouse	AP and SIUPU	Limited spread from the slaughterhouse	Low: condemnation costs

AP: agro-pastoral
SIUPU: semi-intensive, urban–periurban

Impacts of FMD include production losses, lost income due to decreases in sales of milk and live cattle as well as costs related to the control and prevention measures (30). A study evaluating the economic impacts of quarantine restrictions due to FMD outbreaks in cattle in Nakaseke district (an AP region) estimated a forgone income of US$ 5.05 million in live animal sales in livestock markets and US$ 0.55 million in milk sales at the farm gate over a six-month quarantine period (31). From the annual performance reports of MAAIF, Uganda spends about US$ 1.05 million to purchase FMD vaccines per quarter with an additional surveillance and monitoring budget of about US$ 5,300 provided at MAAIF. About the same budget for surveillance is supplemented by development.

Risk estimation

The risk of FMD spread in Uganda through pastoral and trade-related cattle movements from the country's southern border districts varies according to the exposure pathway and production system involved, with higher risk associated with exposure to cattle raised in AP systems (Table VI).

Table VI

Estimation of the risk of foot and mouth disease virus spread in Uganda through pastoral and trade-related cattle movements from the country's southern border districts

Likelihood of entry to destination districts from border districts	Likelihood of exposure in the destination districts	Most likely outcome scenario	Impact: description of consequences
Likelihood of FMDV entry through cattle trade = High	Likelihood of exposure when cattle are introduced for breeding in AP areas = High	Outbreaks on several farms or districts countrywide	High: quarantine restrictions, control costs, production losses
	Likelihood of exposure when cattle are introduced for breeding in SIUPU areas = Moderate	Outbreaks on a single farm	Low: control costs, production losses
	Likelihood of exposure when cattle are introduced in slaughterhouses in AP and SIUPU areas = Low	Outbreak or FMD spread from the slaughterhouse	Low: condemnation costs
Likelihood of FMDV entry through grazing/transhumance = High	Likelihood of exposure when cattle are introduced for grazing in AP areas = High	Outbreaks on several farms in the whole district	High: quarantine restrictions, control costs, production losses
	Likelihood of exposure when cattle are introduced for grazing in SIUPU areas = Low	Outbreaks on a single farm	Low: control costs, production losses

AP: agro-pastoral
FMD: foot and mouth disease
FMDV: foot and mouth disease virus
SIUPU: semi-intensive, urban–periurban

Discussion

The negative socio-economic impacts of FMD in Uganda, including the losses of lucrative international trade, especially export of live animals and animal products, reduced production, changes in herd structure and disease control efforts, are significant and have been studied in recent years but are yet to be estimated in detail. The regular occurrence of FMD in Isingiro and Rakai has been attributed to inadequate biosecurity, low herd immunity and poorly controlled animal movements (32). For example, both large- and small-scale farms have permeable fences and only about 40% have secure gates (15, 33). Some livestock farmers in the area own cattle farms in both southern Uganda and northern Tanzania, and they undertake regular unauthorised cross-border movements of cattle (e.g. DVO Isingiro, personal communication).

In this assessment, the overall likelihood of entry of FMD-infected cattle from the UG–TZ border to AP and SIUPU areas of Uganda was found to be high, mainly due to regular pastoral and trade-related livestock movement, limited veterinary inspections and low vaccination coverage. This agrees with other studies highlighting animal movement and introduction of infected animals to new areas as major risk factors for FMD spread (1), and revealing that regions near international borders and pastoralism are associated with increased likelihood of FMD seropositivity in cattle herds (5).

The overall likelihood of exposure of susceptible cattle to FMDV in the destination areas was found to be high. Most of the animals are susceptible to infection owing to limited vaccination coverage; FMD vaccine is not available for private purchase in Uganda. The vaccine doses provided by the Government are typically sufficient to vaccinate less than 10% of the susceptible cattle population with only a single dose (24, 34). Indeed, MAAIF records indicated that, on average, only 10.3% of cattle were vaccinated within districts that reported outbreaks during the study period. Vaccination is implemented in response to reported outbreaks and is limited to a 20-km radius around the index case (34). Currently, there is no standardised protocol in

place for this ring vaccination strategy, although the MAAIF FMD control and prevention guidelines state that cattle aged six months and above are targeted for vaccination. A quadrivalent vaccine containing O, A, SAT 1 and SAT 2 serotypes, manufactured by the Kenya Veterinary Vaccine Production Institute, is used; however, analysis to confirm that the vaccine is effective against the causative strains is performed only occasionally (34).

To maximise the use and impact of the limited resources available, this study suggests that vaccination should be targeted according to the level of risk. Vaccination should therefore prioritise the AP districts from which movements of large volumes of cattle to other areas originate. Specific communication and awareness campaigns should be intensified in destination districts. At farm level, vaccination should target cattle moving for grazing or breeding as opposed to those moving for slaughter.

In the cattle trade value chain, the movement of cattle directly for slaughter is associated with a low risk of FMD spread to other areas. The risk is minimised in the slaughterhouse because there is no direct contact between susceptible species in the area and live animals and animal products at the site. Among the animals traded, the vast majority (71%) are destined for slaughter in urban areas which have a low cattle density. The few people who have cattle have between one and five animals with a higher level of biosecurity. Even if FMDV is spread by slaughterhouse personnel, it would be unlikely to spread widely. If slaughterhouse personnel adhere to sanitary and biosecurity measures, including wearing appropriate personal protective equipment and conducting adequate cleaning and disinfection procedures, the risk of FMD transmission through this pathway would be reduced further. Nevertheless, transportation vehicles are often shared between live animals destined for slaughter and those destined for breeding. These vehicles pose a potential risk, especially if adequate cleaning and disinfection procedures are not applied; however, evaluation of this aspect of FMDV spread was beyond the scope of this study.

While this study showed that there is a high risk of FMDV spread associated with movements of live cattle from the UG–TZ border to other parts of Uganda, it is not clear how important this spread is in the context of all FMD outbreaks in Uganda. This could be clarified through risk assessments of other purported hotspots, as well as through regular and appropriate outbreak investigations following epidemiological investigation procedures, strengthened surveillance procedures and field research to identify specific risk factors. Circulating viral strains should also be routinely monitored through representative samples collected from outbreaks that occur in different geographical areas and husbandry systems, and in particular where potential vaccine failure is suspected. Furthermore, as suggested by Muleme *et al.*, adequate virus serotyping, subtyping and vaccine matching need to be conducted regularly to ensure that the FMD vaccine used is effective (34).

There is also a higher likelihood of FMDV transmission through unofficial cattle movements, especially at night when veterinary inspectors are not at work. According to veterinary inspection reports in MAAIF, this unofficial cattle movement represents about 10% of the cattle traded. This study, however, could not establish the volume of cattle movements across international borders and the volume of livestock movements for grazing in the districts of origin and destination.

This study will inform the development of risk-based control options for FMD within the framework of an ongoing revision and updating of the national RBSP. As risk dynamics change, regular risk assessments should be planned and conducted. Uganda plans to advance to PCP-FMD stage 3 by 2025, with the development of an official control programme aimed at eliminating FMDV circulation in the domestic susceptible animal population from at least a zone of the country. This progression is important to reduce the impacts of FMD and enable Uganda to realise the potential of its livestock resources and access lucrative markets.

Conclusions

Conclusions are derived from the official (legal) cattle movements recorded through livestock markets, the information provided by the key informants and using outbreaks that were officially reported during the study period. It is clear from the cattle trade connections and the structure of the cattle value chain that the spread of FMD should be prevented at source to minimise the impacts beyond places of origin. Efforts are underway to improve on-farm biosecurity and awareness of FMD. Improvement of cattle market infrastructure is key in controlling FMD spread. Livestock markets should have crushes to facilitate proper physical examination of animals and isolation units to allow segregation of FMD suspected animals. Where resources permit, construction of holding grounds along major stock routes, recruitment of veterinary inspectors and facilitation to allow them to perform inspections effectively, collect appropriate samples from FMD suspected cases and submit them for timely laboratory confirmation are required. More collaboration between local Government staff and those at central level in enforcing animal movement control regulations is necessary.

Acknowledgements

This work was initiated in the 'Risk Analysis to Support Safe Trade and FMD Control' regional training course, supported by the Intergovernmental Authority on Development (IGAD) Centre for Pastoral Areas and Livestock Development (Regional Pastoral Livelihoods Resilience Project), and facilitated by the European Commission for the Control of Foot-and-Mouth Disease (EuFMD). The authors wish to acknowledge the OIE Sub-Regional Representation for Eastern Africa and the Horn of Africa, based in Nairobi, Kenya, for providing experts and reference material for this regional training course, and the FAO Regional Emergency Centre for Transboundary Animal Diseases (ECTAD) office in Nairobi. Finally, the authors are very grateful to Dr Anna Rose Ademun Okurut, Chief Veterinary Officer of Uganda, for granting access to Ministry data.

References

1. Kerfua S.D., Shirima G., Kusiluka L., Ayebazibwe C., Mwebe R., Cleaveland S. & Haydon D. (2018). – Spatial and temporal distribution of foot-and-mouth disease in four districts situated along the Uganda-Tanzania border: implications for cross-border efforts in disease control. *Onderstepoort J. Vet. Res.*, **85** (1), a1528. https://doi.org/10.4102/ojvr.v85i1.1528.

2. Knight-Jones T.J.D. & Rushton J. (2013). – The economic impacts of foot and mouth disease: What are they, how big are they and where do they occur? *Prev. Vet. Med.*, **112** (3–4), 161–173. https://doi.org/10.1016/j.prevetmed.2013.07.013.

3. Mwiine F.N., Ayebazibwe C., Olaho-Mukani W., Alexandersen S. & Tjørnehøj K. (2010). – Prevalence of antibodies against foot-and-mouth disease virus in cattle in Kasese and Bushenyi districts in Uganda. *Int. J. Anim. Vet. Adv.*, **2** (3), 89–96. Available at: https://core.ac.uk/download/pdf/13737257.pdf (accessed on 3 June 2021).

4. Mwiine F.N., Velazquez-Salinas L. […] & Rieder E. (2019). – Serological and phylogenetic characterization of foot and mouth disease viruses from Uganda during cross-sectional surveillance study in cattle between 2014 and 2017. *Transbound. Emerg. Dis.*, **66** (5), 2011–2024. https://doi.org/10.1111/tbed.13249.

5. Munsey A., Mwiine F.N., Ochwo S., Velazquez-Salinas L., Ahmed Z., Maree F., Rodriguez L.L., Rieder E., Perez A. & VanderWaal K. (2019). – Spatial distribution and risk factors for foot and mouth disease virus in Uganda: opportunities for strategic surveillance. *Prev. Vet. Med.*, **171**, 104766. https://doi.org/10.1016/j.prevetmed.2019.104766.

6. National Planning Authority (NPA) (2020). – Third National Development Plan (NDPIII) 2020/2021–2024/2025. NPA, Kampala, Uganda, 311 pp. Available at: www.npa.go.ug/wp-content/uploads/2020/08/NDPIII-Finale_Compressed.pdf (accessed on 12 July 2021).

7. World Organisation for Animal Health (OIE) & Food and Agriculture Organization of the United Nations (FAO) (2012). – The Global Foot and Mouth Disease Control Strategy: Strengthening Animal Health Systems Through Improved Control of Major Diseases. OIE, Paris, France & FAO, Rome, Italy, 253 pp. Available at: https://doc.oie.int/dyn/portal/index.xhtml?page=alo&aloId=18691&req=5&cid=01ef01d5-a674-4fb0-8c4b-5334cac5dea8 (accessed on 12 July 2021).

8. Food and Agriculture Organization of the United Nations (FAO), World Organisation for Animal Health (OIE) & European Commission for the Control of Foot-and-Mouth Disease (EuFMD) (2018). – The Progressive Control Pathway for Foot and Mouth Disease Control (PCP-FMD): Principles, Stage Descriptions and Standards. 2nd Ed. FAO, Rome, Italy; OIE, Paris, France & EuFMD, Rome, Italy, 24 pp. Available at: www.fao.org/3/CA1331EN/ca1331en.pdf (accessed on 30 July 2021).

9. Kutamba W. & Musasizi A. (2019). – Pastoralists cry foul over cattle movement ban. Article published in the Cattle Site. Available at: www.thecattlesite.com/news/53852/pastoralists-cry-foul-over-cattle-movement-ban/ (accessed on 12 July 2021).

10. World Organisation for Animal Health (OIE) (2010). – Handbook on Import Risk Analysis for Animals and Animal Products. Vol. 1: Introduction and Qualitative Risk Analysis. 2nd Ed. OIE, Paris, France, 88 pp. Available at: https://doc.oie.int/dyn/portal/index.xhtml?page=alo&aloId=18684 (accessed on 30 July 2021).

11. Moutou F., Dufour B. & Ivanov Y. (2001). – A qualitative assessment of the risk of introducing foot and mouth disease into Russia and Europe from Georgia, Armenia and Azerbaijan. *Rev. Sci. Tech. Off. Int. Epiz.*, **20** (3), 723–730. https://doi.org/10.20506/rst.20.3.1307.

12. Fournié G., Jones B.A., Beauvais W., Lubroth J., Njeumi F., Cameron A. & Pfeiffer D.U. (2014). – The risk of rinderpest re-introduction in post-eradication era. *Prev. Vet. Med.*, **113** (2), 175–184. https://doi.org/10.1016/j.prevetmed.2013.11.001.

13. Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) & Uganda Bureau of Statistics (UBOS) (2009). – The National Livestock Census: a summary report of the National Livestock Census, 2008. MAAIF, Entebbe, Uganda & UBOS, Kampala, Uganda, 34 pp. Available at: www.google.fr/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwj2pdWHl_7wAhWD2uAKHX6qA9cQFjABegQIAxAD&url=https%3A%2F%2Fcatalog.ihsn.org%2Findex.php%2Fcatalog%2F3788%2Fdownload%2F52466&usg=AOvVaw2JE627_FKQtNo1q7ceqYXa (accessed on 4 June 2021).

14. Food and Agriculture Organization of the United Nations (FAO) (2018). – Livestock Production Systems Spotlight – Uganda: Chicken Meat and Beef. FAO, Rome, Italy, 10 pp. Available at: www.fao.org/3/i8713en/i8713en.pdf (accessed on 4 June 2021).

15. Baluka S.A., Ocaido M. & Mugisha A. (2014). – Prevalence and economic importance of foot and mouth disease, and contagious bovine pleuropneumonia outbreaks in cattle in Isingiro and Nakasongola districts of Uganda. *Discourse J. Agric. Food Sci.*, **2** (4), 107–117. Available at: www.resjournals.org/JAFS/PDF/2014/Apr/Baluka_et_al.pdf (accessed on 20 February 2020).

16. Mpairwe D., Zziwa E., Mugasi S.K. & Laswai G.H. (2015). – Characterizing beef cattle value chains in agro-pastoral communities of Uganda's Lake Victoria Basin. *Front. Sci.*, **5** (1), 1–8. Available at: http://article.sapub.org/10.5923.j.fs.20150501.01.html (accessed on 8 June 2021).

17. Nation Media Editorial Team (2018). – Meat prices shoot up amid ban on cattle transportation. Press article published in the Daily Monitor. Available at: www.monitor.co.ug/uganda/business/finance/meat-prices-shoot-up-amid-ban-on-cattle-transportation-1776322 (accessed on 12 July 2021).

18. Kiwawulo C., Atuhairwe R., Ayoreka A., Kiwanuka F., Buregyeya D., Kasirye J., Masaba S., Wanyama O. & Magere D. (2020). – Security, local leaders linked to cattle thefts. Press article published in the New Vision. Available at: www.newvision.co.ug/articledetails/97977 (accessed on 7 July 2021).

19. World Organisation for Animal Health (OIE) (2021). – Disease situation. OIE–World Animal Health Information System (WAHIS) Interface. OIE, Paris, France. Available at: https://wahis.oie.int/#/dashboards/country-or-disease-dashboard (accessed on 11 July 2021).

20. Dhikusooka M.T., Ayebazibwe C., Namatovu A., Belsham G.J., Siegismund H.R., Wekesa S.N., Balinda S.N., Muwanika V.B. & Tjørnehøj K. (2016). – Unrecognized circulation of SAT 1 foot-and-mouth disease virus in cattle herds around Queen Elizabeth National Park in Uganda. *BMC Vet. Res.*, **12**, 5. https://doi.org/10.1186/s12917-015-0616-1.

21. Idriss O. & Nersy C. (2017). – Pastoralism: opportunities for livestock and challenges for Veterinary Services. *In* Technical Item 22nd Conference of the OIE Regional Commission for Africa, 20–24 February, Swakopmund, Namibia. World Organisation for Animal Health (OIE), Paris, France, 21 pp. https://doi.org/10.20506/TT.2655.

22. Ministry of Public Service (MoPS) (2011). – Job Descriptions and Specifications for Jobs in Local Governments. MoPS, Kampala, Uganda, 482 pp. Available at: https://psc.go.ug/sites/default/files/downloads/Local Government Job Description .pdf (accessed on 11 July 2021).

23. Wesonga W.S.N., Madasi B. & Nambo E. (2018). – Factors associated with a low veterinary regulatory compliance in Uganda, their impact and quality management approaches to improve performance. *Open J. Vet. Med.*, **8** (12), 207–231. https://doi.org/10.4236/ojvm.2018.812019.

24. Wolff C., Abigaba S. & Sternberg Lewerin S. (2019). – Ugandan cattle farmers' perceived needs of disease prevention and strategies to improve biosecurity. *BMC Vet. Res.*, **15** (1), 208. https://doi.org/10.1186/s12917-019-1961-2.

25. Mwebaze S.M.N. (2006). – Country Pasture/Forage Resource Profiles: Uganda. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy, 17 pp. Available at: https://ees.kuleuven.be/klimos/toolkit/documents/660_Uganda_English.pdf (accessed on 11 July 2021).

26. Wolff C., Boqvist S., Ståhl K., Masembe C. & Sternberg-Lewerin S. (2017). – Biosecurity aspects of cattle production in western Uganda, and associations with seroprevalence of brucellosis, salmonellosis and bovine viral diarrhoea. *BMC Vet. Res.*, **13** (1), 382. https://doi.org/10.1186/s12917-017-1306-y.

27. Mielke S.R. & Garabed R. (2020). – Environmental persistence of foot-and-mouth disease virus applied to endemic regions. *Transbound. Emerg. Dis.*, **67** (2), 543–554. https://doi.org/10.1111/tbed.13383.

28. Radostits O., Gay C., Hinchcliff K. & Constable P. (2006). – Veterinary Medicine. 10th Ed. Saunders, New York, United States of America, 2180 pp.

29. Okello E. (2019). – Drought kills 200 cows in Hoima. Press article published in the Uganda Radio Network. Available at: https://ugandaradionetwork.net/story/drought-kills-200-cows-in-hoima (accessed on 21 March 2020).

30. Baluka S.A. (2016). – Economic effects of foot and mouth disease outbreaks along the cattle marketing chain in Uganda. *Vet. World*, **9** (6), 544–553. https://doi.org/10.14202/vetworld.2016.544-553.

31. The Nyama Platform (2014). – Position Paper on the Foot and Mouth Disease (FMD) Epidemic in Uganda. AgriProFocus, Kampala, Uganda, 2 pp. Available at: http://images.agri-profocus.nl/upload/150225_Position_Paper_Final1432277526146700 7094.pdf (accessed on 11 July 2021).

32. Kutamba W. (2018). – Government suspends cross border movement of livestock. Press article published in the Daily Monitor. Available at: www.monitor.co.ug/News/National/Government-suspends-cross-border-movement-of-livestock/688334-4708706-4ycb2kz/index.html (accessed on 20 February 2020).

33. Kerfua S.D., Shirima G., Kusiluka L., Ayebazibwe C., Mwebe R., Cleaveland S. & Haydon D.T. (2018). – Retrospective FMD outbreak reports from Uganda and Tanzania border districts (2011–2016): implications for FMD control by vaccination. *In* Proc. European Commission for the Control of Foot-and-Mouth Disease (EuFMD) Standing Technical Committee, 29–31 October, Puglia, Italy, 12 pp. Available at: www.fao.org/fileadmin/user_upload/eufmd_new/docs/Meeting_documents/Open_Session_2018/11B.1_-_Kerfua.pdf (accessed on 11 July 2021).

34. Muleme M., Barigye R., Khaitsa M.L., Berry E., Wamono A.W. & Ayebazibwe C. (2012). – Effectiveness of vaccines and vaccination programs for the control of foot-and-mouth disease in Uganda, 2001–2010. *Trop. Anim. Health Prod.*, **45** (1), 35–43. https://doi.org/10.1007/s11250-012-0254-6.