

# Rift Valley fever:

## Challenges and new insights for prevention and control using the “One Health” approach

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“Solidarity doesn’t always mean money; it could be a research finding that can improve the life of our community”.

**- Osama Ahmed Hassan Ahmed**

*Dedicated to the vulnerable groups that suffer from Rift Valley fever*

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# Prologue

I have witnessed two outbreaks of Rift Valley fever disease. The first was in Saudi Arabia in 2000 and the second was in Sudan in 2007. I have also visited and collaborated with colleagues from Kenya, where Rift Valley fever was first isolated and has since been a major concern for the government.

During the two outbreaks, I saw panic and fear spread among the people. Although they were interested to protect themselves, it was difficult to find information about the disease. A survivor of another Rift Valley fever outbreak told me the following story:

“We were on the way to our animals that were kept outside of the village, then suddenly my friend said he had a fever and he decided to get back to the village. He used a donkey to get back. When he arrived to the village he started having bloody diarrhea with bad odor. The people called for some of our friends to bring their boat as there was very heavy rains that flooded the village. They picked my friend up with the boat and went to the health point, which is located far [15 km] from our village. He stayed there until the evening and we were informed that he died. I could not imagine that we were together in the morning.”

I also saw how the livestock industry was destroyed during the outbreaks and how many of the livestock traders and exporters who did not have insurance went to prison due to bankruptcy associated with the livestock trade embargo. Those people and their families sadly were left alone to face this unexpected destiny.

At that time, I was thinking of how this tragic situation and its severe consequences could be studied in order to learn how to help those vulnerable people in the future. This was the motivation of my One Health approach: to study Rift Valley fever in order to contribute to the life of rural people where Rift Valley fever is commonly spread.

# Abstract

Rift Valley fever (RVF) is an emerging viral zoonosis that causes frequent outbreaks in east Africa and on the Arabian Peninsula. The likelihood of RVF global expansion due to climate change and human anthropogenic factors is an important issue. The causative agent, RVF virus, is an arbovirus that is transmitted by several mosquito species and is able to infect a wide range of livestock as well as people. The infection leads to mass abortions and death in livestock and a potentially deadly hemorrhagic fever in humans. RVF has severe socio-economic consequences such as animal trade bans between countries, disruption of food security, and economic disaster for farmers and pastoralists as well as for countries. Human behavior such as direct contact with infected animals or their fluids and exposure to mosquito bites increases the risk for contracting the disease.

To better understand the challenges associated with RVF outbreaks and to explore prevention and control strategies, we used the One Health approach. The local community had to be involved to understand the interaction between the environment, animals, and humans. We focused on Sudan, Saudi Arabia, and Kenya. First, we systematically reviewed the literature and then we performed cross sectional community-based studies using a special One Health questionnaire. Climatic and remote sensing data were used in combination with statistics to develop a sub-region predictive model for RVF.

For both Saudi Arabia and Sudan, the ecology and environment of the affected areas were similar. These areas included irrigation canals and excessive rains that provide an attractive habitat for mosquito vectors to multiply. The surveillance systems were unable to detect the virus in livestock before it spread to humans. Ideally, livestock should serve as sentinels to prevent loss of human lives, but the situation here was reversed. Differences between countries regarding further spread of RVF was mainly determined by better economic and infrastructure resources.

In Sudan, there was a lack of knowledge and appropriate practices at the studied community regarding RVF disease symptoms and risk factors for both animals and humans. The community was hesitant in notifying the authorities about RVF suspicion in livestock due to the lack of a compensation system. The perceived role of the community in controlling RVF was fragmented, increasing the probability of RVF transmission and disease.

In Kenya, our study found that better knowledge about RVF does not always translate to more appropriate practices that avoid exposure to the disease. However, the combination of good knowledge, attitudes, and practices may explain why certain communities were less affected. Strategies to combat RVF should consider socio-cultural and behavioral differences among communities. We also noticed that RVF outbreaks in Kenya occurred in regions with high livestock density exposed to heavy rains and wet soil fluxes, which could be measured by evapotranspiration and vegetation seasonality variables. We developed a RVF risk map on a sub-regional scale. Future outbreaks could be better managed if such relevant RVF variables are integrated into early warning systems.

To confront RVF outbreaks, a policy is needed that better incorporates ecological factors and human interactions with livestock and environment that help the RVF pathogen spread. Early detection and notification of RVF is essential because a delay will threaten the core of International Health Regulations (IHR), which emphasizes the share of information during a transboundary disease outbreak to avoid unnecessary geographical expansion.

**Keywords.** Rift Valley fever, Sociocultural practices, Community involvement, Ecological factors, Risk map, Early warning system, Surveillance system, International Health Regulations, and One Health approach.

# Sammanfattning på svenska (summary in Swedish)

Rift Valley feber (RVF) är en virussjukdom som sprids med myggor till både människor och djur. RVF orsakar utbrott i Afrika och på den arabiska halvön. Som för andra myggburna virus finns en risk för spridning till andra delar av världen, via mygg, transporter av djur, människors beteende och klimatförändringar. Det är viktigt att undersöka vilka faktorer som avgör smittspridning, både i de områden där RVF nu förekommer och i de delar av världen som har störst risk att drabbas, så att motåtgärder kan förberedas.

Om vi människor blir infekterade med RVF virus kan det bl.a. orsaka dödlig blödarfeber och missfall, och boskap drabbas av massdöd och aborter. Ett RVF utbrott har också allvarliga indirekta konsekvenser, som t.ex. förbud att exportera och sälja boskap, vilket leder till ekonomiska förluster och matbrist för både drabbade länder och de lokalsamhällen som är helt beroende av sin boskap. Förutom att myggor överför RVF virus, så kan det spridas direkt från infekterad boskap till människor och hur man agerar och betar sig har stor betydelse för om man blir smittad. Riskfaktorer för RVF är bl.a. direktkontakt med boskap, egen slakt, egen mjölkning och myggbett.

För att bättre förstå orsakerna till RVF utbrott och undersöka strategier för att förhindra och kontrollera sjukdomsutbrott, så använde vi en metod som kallas "One Health" (en hälsa). Vi, det vill säga människor, djur, växter och miljö, är alla beroende av varandra så därför går "One Health" ut på att se helheten. Det är viktigt att skapa ett samarbete mellan människohälsa, djurhälsa, ekologer, entomologer, socionomer och alla vetenskaper som kan bidra till att sjukdomsutbrott minskas och kontrolleras. För att studera alla faktorer som bidrar till hur RVF sprids, så måste man studera människor, djur, myggor, ekologin, klimatet, beteende osv.

Vi genomförde den beteendevetenskapliga delen av studien i samhällen och byar i avlägsna områden i Sudan och Kenya där RVF drabbar hårdast, men där den också kan stoppas i ett tidigt stadium. Vi genomförde också jämförande, systematiska studier av tidigare RVF utbrott i ett land med god ekonomisk situation (Saudiarabien) och i ett land med begränsade resurser (Sudan). Dessutom använde vi satellit- och väderdata i kombination med statistik för att utveckla en RVF riskkarta, för att bättre förstå vilka ekologiska förhållanden som ökar risken för RVF utbrott.

För både Saudiarabien och Sudan så var ekologin och miljön likartad i utbrottsområdena. Det fanns bevattningskanaler och det förekom kraftiga regn som ökade antalet myggor. De existerande övervakningssystemen kunde inte varna för RVF, utan utbrotten upptäcktes inte förrän många människor insjuknade. Vi såg att boskap drabbas oftast före människor och med ett fungerande övervakningssystem med provtagning av boskap så skulle man få en tidig varning för ett förestående utbrott. De undersökta länderna skilde sig i sin hantering av utbrottet. Saudiarabien bekräftade utbrottet inom 18 dagar, det tog tre gånger så lång tid i Sudan. Det fanns än bättre infrastruktur och mer resurser i Saudiarabien, vilket gjorde att utbrottet bekämpades fortare och senare utbrott har motverkats jämfört med Sudan.

När vi med hjälp av enkäter undersökte kunskap om RVF och beteende under utbrott hos människor i byar i avlägsna delar av Sudan så fann vi att kunskapsnivån om RVF generellt var låg. En majoritet av den undersökta befolkningen betedde sig så att risken för RVF infektion snarare ökade för både människor och boskap. Enligt vår undersökning var byborna mycket tveksamma när det gällde att meddela myndigheterna om ett utbrott, eftersom det inte finns någon ekonomisk kompensation och vid ett utbrott så får inte boskapen säljas och den måste nödslaktas. I Kenya upptäckte vi att god kunskap om RVF inte alltid betyder att människorna undviker ett riskbeteende. Här jämförde vi tre olika kulturer och det viktigaste för att undvika att bli smittad och sprida RVF vidare, var en kombination av god kunskap, bra attityder och rätt beteende. Detta skilde sig mellan de olika kulturerna. Kulturella- och beteendeskillnader måste beaktas när strategier för att förhindra RVF utbrott utarbetas.

Genom analyser av satellitdata, förekomst av boskap och markens beskaffenhet så kunde vi visa att RVF utbrott i Kenya uppträdde i regioner med mycket boskap, fuktig mark, regn och kraftig vegetationsökning under regnperioden. Dessa områden hade dessutom ofta en viss jordartstyp. För att bättre planera var framtida utbrott kan förekomma bör dessa faktorer användas för att konstruera RVF riskkartor.

För att begränsa och kontrollera RVF utbrott i framtiden, så måste en policy utformas som tar hänsyn till de faktorer som främjar RVF spridning och smitta, dvs. ekologiska faktorer samt människors interaktion med djur och miljö. Tidig upptäckt och anmälan av RVF är avgörande för smittspridningskontroll, annars kommer fördröjningen att leda till ökat lidande och global expansion.

# Contributing papers

This thesis is based on the following papers.

1. **Hassan OA**, Ahlm C, Sang R, Evander M. The 2007 Rift Valley fever outbreak in Sudan. *PLoS Negl Trop Dis* 2011, 5(9): e1229.
2. **Hassan OA**, Ahlm C, Evander M. A need for One Health approach - lessons learned from outbreaks of Rift Valley fever in Saudi Arabia and Sudan. *Infect Ecol Epidemiol.* 2014, 4: 20710-
3. Mosomtai G, Evander M, Sandström P, Ahlm C, Sang R, **Hassan OA**, Affognon H, Landmann T. Association of ecological factors with Rift Valley fever occurrence and mapping of risk zones in Kenya. *Int J Inf Dis.* 2016, 46:49-55.
4. **Hassan OA**, Affognon H, Rocklöv J, Mburu P, Sang R, Ahlm C, Evander M. One Health approach to identify knowledge, attitudes and practices that affect community involvement in the control of Rift Valley fever outbreaks. (Resubmission process, *PLoS Negl Trop Dis*)
5. Affognon H, Mburu P, **Hassan OA**, Kingori S, Ahlm C, Sang R, Evander M. Sociocultural differences affect Rift Valley fever exposure. (Resubmission process, *PLoS Negl Trop Dis*).

# Thesis objectives

The overall objective of this thesis is to better understand the challenges associated with RVF outbreaks and to explore new prevention and control strategies for emerging RVF outbreaks from the One Health perspective. This thesis has the following specific objectives:

- 1- To summarize the knowledge of RVFV in Sudan.
- 2- To compare two major outbreaks of RVF in Saudi Arabia (2000) and Sudan (2007).
- 3- To investigate, using a bottom-up approach, knowledge, attitudes, and practices of RVF in an agro-pastoralist community in Sudan.
- 4- To assess RVF exposure from a sociocultural perspective in a multi-community region in Kenya known to experience RVF outbreaks.
- 5- To identify ecological factors that explain the risk of RVF outbreaks in eastern and central Kenya and to produce a spatially explicit risk map.





# Introduction

## Background

The world population is expected to increase to 9.6 billion by 2050, a demographic trend that will inevitably increase livestock production [1]. This increase in population will also require an additional 31 million hectares of crops to secure food for both livestock and humans [1]. Encroachment of livestock and humans into unpopulated ecological systems might change the pattern of existing zoonotic diseases and expose humans to unfamiliar or new pathogens [2]. Emerging and re-emerging viral diseases have recently been in the spotlight as significant outbreaks have become more frequent [3-8]. The majority of these outbreaks are zoonotic and many of them, such as the Rift Valley fever (RVF) in Africa [5, 9-15], threaten the health of both animals and humans. The recent 2006-2008 RVF outbreaks in Kenya, Tanzania, Somalia, Sudan, and Madagascar resulted in about 230,000 human cases [16]. In addition, RVF has a potential to spread globally due to climate change and anthropogenic factors [17-20]. In many cases, RVF could lead to significant human and livestock death, resulting in severe socio-economic impacts such as livestock trade bans between countries, disruption of food security, and economic disaster for countries as well as farmers [21, 22].

As RVF can result in such significant disruptions, the Global Outbreak and Response Network (GOARN) carefully monitors RVF outbreaks [23]. In addition, RVF is on the list of zoonotic diseases monitored by the Global Early Warning System (GLEWS) for major animal diseases, including zoonoses. As RVF presents such a significant threat, GOARN, GLEWS, the Food and Agriculture Organization of the United Nations (FAO), the World Organization for Animal Health (OIE), and the World Health Organization (WHO) [24] share information about the disease. Accordingly, regional and international collaborations and networks for RVF preparedness for prevention and control are a priority [25-27].

## Nature of the disease and risk factors

The Rift Valley fever virus (RVFV), a three-segmented RNA virus, belongs to the *Phlebovirus* genus of the *Bunyaviridae* family. The *Bunyaviridae* family includes viruses that cause many other serious diseases in both animals and humans [17, 28-33]. RVF is an arthropod borne viral (arboviral) disease transmitted via mosquitoes. *Aedes* and *Culex* genera, the primary and

secondary mosquito vectors, transmit the virus between animals or from viremic animals to humans [34-40] (Figure 1). Vertical transmission from adult mosquitoes to offspring is believed to be a mechanism of virus maintenance during inter-epidemic periods [41, 42]. Mosquito activity and by extension RVF exposure is influenced by environmental factors such as high temperatures and heavy precipitation [16, 43, 44]. Many RVF outbreaks have been reported after heavy rains [18, 37, 41, 45-48] or after implementing water resource management projects such as irrigation schemes or river deltas linked to new dam construction in Egypt and Senegal [44, 49]. All these ecological changes can create suitable habitats for mosquitoes, increasing the likelihood of RVF outbreaks.

RVFV infects and causes disease in humans as well as livestock (e.g., sheep, goat, cattle, and camel) [28, 29]. Several studies have suggested that many wildlife species (e.g., the African buffalo, rodents, bats, and monkeys) are affected by RVFV, but it is unclear if these species act as reservoirs of RVFV during inter-epidemic seasons [28, 50-52]. The wildlife/livestock interface that occurs when animals are grazing is a potential risk for RVFV infection of livestock [53]. Human behaviour, such as direct contact with infected animals or their fluids and particularly aborted animals, and being exposed to infected mosquitos increase the risk of being infected by RVFV [54-56] (Figure 1).

In animals, the manifestation of RVF is associated with abortion storms and a high mortality in young animals [28, 29]. In humans, the disease could be a short acute febrile or flu-like syndrome, but it could also be severe and cause encephalitis, haemorrhagic fever, blindness, hepato-renal failure, and ultimately death [56-60].

## **Rift Valley fever vaccine**

There is no approved RVF vaccine for humans [56], and the vaccines used for animals are either inactivated or live attenuated [61, 62]. However, the inactivated vaccine needs multiple doses to booster immunity, making it more expensive and more difficult to distribute. Because the vaccine requires multiple shots, establishing immunity requires time and this vulnerability decreases the vaccine's usefulness during outbreaks. The live attenuated vaccine is administered as a single dose, but it has shown some teratogenic effects that can lead to abortion among inoculated pregnant animals [17, 28, 44, 61]. However, safe vaccines remain the effective way to protect animals and humans [62-64].

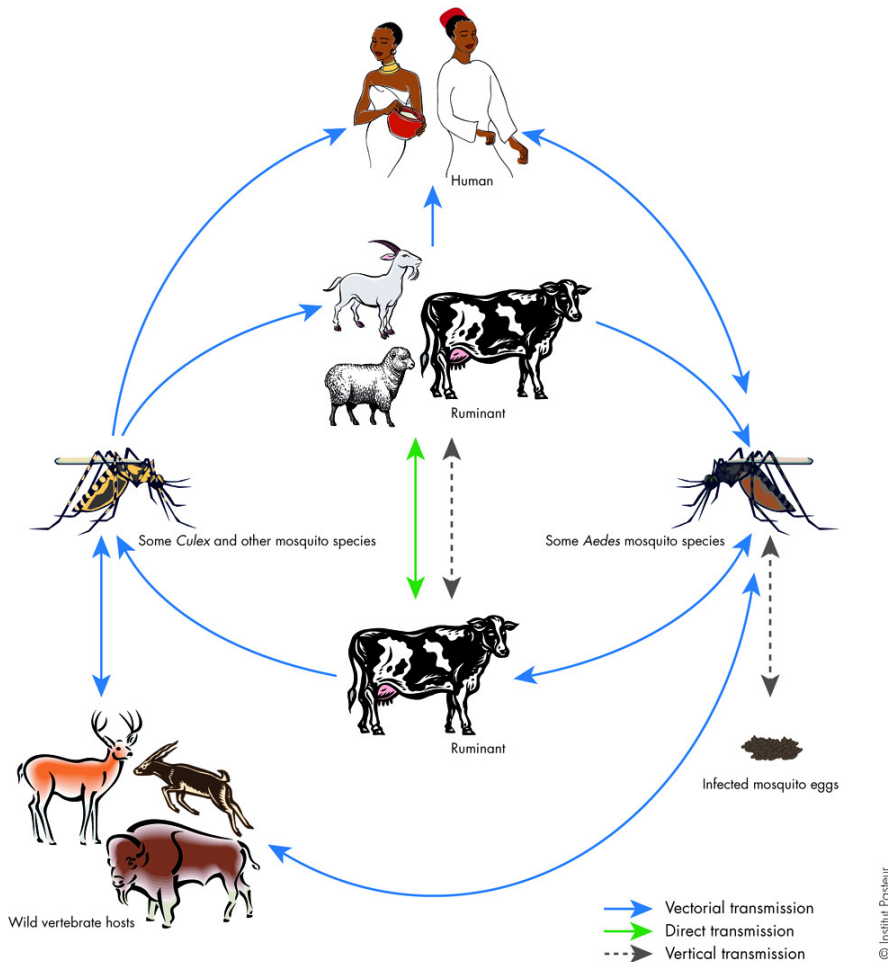


Figure 1. Rift Valley fever transmission [65]

## Prediction models for RVF outbreak

We use the WHO's definition of an outbreak:

“A disease outbreak is the occurrence of cases of disease in excess of what would normally be expected in a defined community, geographical area or season. An outbreak may occur in a restricted geographical area, or may extend over several countries. It may last for a few days or weeks or several years. A single case of a communicable disease long absent from a population, or caused by an agent (e.g.,

bacterium or virus) not previously recognized in that community or area, or the emergence of a previously unknown disease may also constitute an outbreak and should be reported and investigated [66]”.

Because of the serious effects of RVF outbreaks and the limitations of the vaccines, outbreak predictions have been seen as a priority when directing prevention and control measures on the ground [38, 67, 68]. Prediction models have been established using climate and remote sensing data to detect early conditions associated with RVF outbreaks [43, 69, 70].

Climate models mainly focus on vector activity as a product of specific climate conditions and rarely include data from the ground – e.g., socioeconomic status, vaccination coverage for animals, and animal movement – as potential amplifiers of RVFV [16, 18]. Moreover, these models do not consider the interface between animals and humans, which could play a major role in outbreak emergence [16]. A comprehensive integrated prediction system requires including such data, but the cost of implementation and data management must be affordable [18]. Furthermore, most of the successful prediction models for RVF outbreaks are based on data collected from Kenya (east Africa) or Mauritania and Senegal (west Africa), making the generalizability challenging [38, 43]. The broad scale of these models could lead to less accuracy. For example, models of RVF outbreak in Sudan, Madagascar, and South Africa predict true cases of RVF to be 50%, 23%, and 20%, respectively [16].

Three conditions need to be present for a RVF outbreak to occur: abundant numbers of competent vectors (i.e., mosquitoes), an adequate number of susceptible animals and humans (i.e., no herd immunity), and a suitable ecology [17, 44]. Therefore, the prediction models should act as an early warning system. With the help of these models, surveillance systems could be set in place to detect RVFV circulation in mosquitoes and livestock before it is transmitted to humans on a large scale [16]. Accordingly, prevention and control measures should be organized as an integrated management system, including the control of competent vectors, the distribution of animal vaccinations, and the restriction of livestock movement [16].

## **Geographical distribution of RVFV**

Since the first isolation of RVFV in Kenya in 1930 [71], RVF has dispersed to geographical regions both in and outside Africa [17, 32, 72-74]. The virus has caused outbreaks with devastating health and socio-economic impacts in east Africa (Kenya, Tanzania, and Somalia) [74-76], west Africa (Senegal and

Mauritania) [49, 77-79], central and north Africa (Sudan and Egypt) [80-82], and south Africa (Zambia, Zimbabwe, and the Republic of South Africa) [83-85]. Outside Africa RVFV outbreaks have occurred in the Indian Ocean region (Madagascar, Mayotte, and Comoros) [47, 65, 86, 87] and on the Arabian peninsula (Saudi Arabia and Yemen) [37, 88] (Figure 2). The majority of the countries share borders and some of them even experienced RVF outbreaks simultaneously, such as the 1997 RVF outbreak of Mauritania and Senegal and the 2000 RVF outbreak in Yemen and Saudi Arabia [88, 89] (Figure 2). Furthermore, serological surveys have shown that RVFV circulates in most of the other sub-Saharan African countries in a cryptic cycle. Recently, circulation of RVFV has been shown in Tunisia, located near southern Europe [90, 91] (Figure 2). RVFV is present in a variety of ecological zones, such as semi-arid or wetlands (dambos) in Kenya and South Africa, irrigated land in Egypt, Sudan, and the Senegal River, forest areas in Madagascar, and arid zones in Yemen and north of Senegal [38, 92]. Geographic expansion of RVF could take place by crossing borders, for instance, via livestock trade [33, 92-96] and through mosquito expansion enhanced by climate change [18, 19, 33, 38, 96, 97]. The likelihood of future outbreaks of RVF is an important issue [6] and risk assessment for introduction of RVFV to unaffected regions and the readiness of a surveillance system has been undertaken in many regions around the world including north Africa, Europe, the Mediterranean regions, Australia, Canada, U.S.A., and some Asian countries [98-114].

## **Economic impact**

RVF outbreaks have a significant impact on human health, with the loss of thousands of human lives and high morbidity. The costs for the health sector and control measures are an additional burden for the affected countries. Furthermore, the economic impact of a RVF outbreak exceeds the direct cost of loss of livestock because it will also affect sectors within the livestock industry, but most severely the farming populations in the affected countries. The devastating effect includes the livestock producers, the livestock market chain dealers and consumers, the rural and national economy [21, 22], and even the international livestock trade [21] (Figure 3). For example, the socio-economic impact of RVF outbreaks in Kenya, Tanzania, Somalia, Saudi Arabia, and Yemen collectively led to a loss of up to 470 million US dollars [21]. Understanding the socio-economic impact of RVF will help health care professionals and public policy leaders target the vulnerable groups and enhance their resilience.

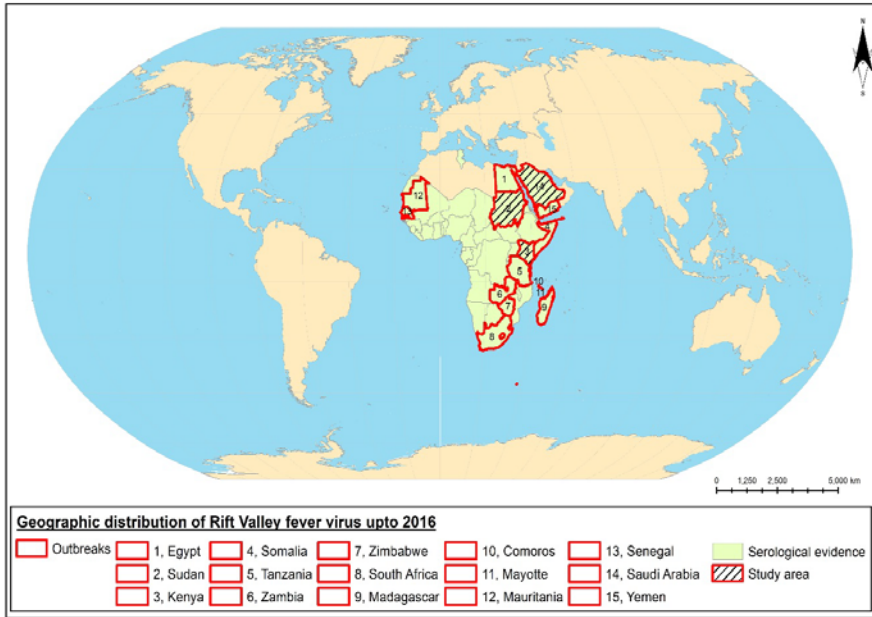


Figure 2. Geographic distribution of Rift Valley fever up to 2016.

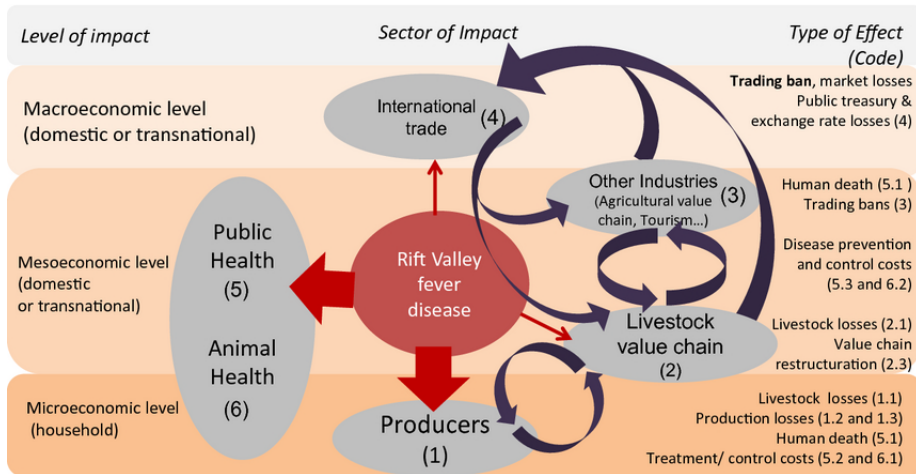


Figure 3. Level and type of socio-economic impacts of Rift Valley fever per sector [21]. The links between the disease and the different sectors and level impacted (health related costs) are represented by straight (red) arrows; the links between the different sectors and level impacted (non-health-related costs) are represented by the bent (blue) arrows.

## **Conceptual framework: One Health approach**

RVF outbreak dynamics are related to the interaction of animals, humans, the RVF virus, and ecological systems [115]. Consequently, controlling RVF requires collaboration among veterinary, medical, environmental, and social sciences [116-118]. In addition, such approaches should consider biodiversity, animal welfare, and human health ethics. Indeed, the One Health approach addresses the idea that animals, humans, and ecosystems are interconnected; furthermore, such a view is especially important in countries with limited resources [2, 119-126]. One Health considers the determinants of disease emergence, for instance, socio-economic and cultural factors that may shape human behaviour and how human behaviour intersects with animals and the environment [117]. This aim aligns with the definition of interdisciplinary research formulated by Committee on Science, Engineering, and Public Policy, National Academies, U.S.A, 2004:

“Interdisciplinary research is a mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of research practice”. [127]

To this end, this thesis is driven by the concept of One Health. We aim to better understand the complexity associated with the prevention and control of RVF outbreaks and use our findings to suggest solutions. The One Health approach was applied from the planning stage, and within this context we formulated our integrated research questions. To avoid a fragmented approach, our One Health questionnaire (Appendix) was designed to collect data about RVF at the human, animal, and environmental interfaces simultaneously. This holistic approach offered us an opportunity to explore whether the knowledge, attitudes, and practices of the local communities allowed them to confront RVF from a One Health perspective and to what extent they could be a part of One Health. One Health recognises that human behaviour influences disease transmission between humans, livestock, and other animals as well as the ecosystem [118].



# Materials and methods

## Study settings

This thesis focuses on three countries – Sudan, Saudi Arabia, and Kenya (Figure 2) – based on their importance in regard to RVF outbreaks to better understand the emergence of the disease inside and outside Africa.

### *Sudan*

Sudan is the third largest country in Africa and the largest in north-eastern Africa with an area of 1,861,484 square km and a population of about 37 million. The majority of population is below 55 years of age and about 33.8% of the population lives in urban areas. The country consists of 18 states and it has a coastline bordering the Red Sea between Egypt and Eritrea and connects Africa with the Middle East. Sudan shares a border with seven countries. It is an agricultural country where most of the lands are suitable for cultivation. The agricultural sector occupies about 80% of the workforce and contributes about 29% of the total country's GDP [128]. It also has a large livestock population estimated to be 104 million heads including sheep, cattle, goat, and camel. The country is dominated by the Nile River and its tributaries, the White Nile and the Blue Nile. In general, the irrigated lands cover around 18,900 square km [128] and there are several dams in the Nile basin.

Sudan has mainly flat plains divided by several mountain ranges. It is located in a tropical zone where the climate is hot and dry and the rain fall varies by region and increases towards the south. The country has a varied ecological zones – desert, semi-arid, savannah, and Mediterranean [129]. The rainy season lasts for about three months (July to September) in the north and up to six months (June to November) in the south. In Sudan, there is no charge for grazing animals and nomads move with their livestock for long distances.

The first RVF outbreaks that occurred in Sudan was in 1973 and 1976 in the White Nile state in the semi-arid zone [130]. In 2007, RVF re-emerged again in the White Nile. However, it dispersed this time to new areas that were not affected in previous episodes and caused the largest RVF outbreak in Sudan up to that date and covered five of 26 (20%) regions [80]. Because the epidemiology of RVF in Sudan has not been well studied, we selected Sudan as a part of our study.



## ***Saudi Arabia***

The Kingdom of Saudi Arabia constitutes 80% of the Arabian Peninsula and shares borders with seven countries. It has a total area of 2,149,690 square km and it is divided into four main regions. The population is about 28 million but 30% of them are work immigrants. The majority of the population are under 55 years old. The urban population is 83% of the total population. Saudi Arabia borders the Arabic Gulf (Persian Gulf) to the east, the Red Sea to the west, and Yemen and Oman to the south. Along the long coastline there are several harbours [128].

Saudi Arabia is an oil-oriented economy and is one of the largest exporters of petroleum in the world. It has no permanent rivers or lakes, but does have dry riverbeds that contain water only during times of heavy rain (wadis). Saudi Arabia has a desert climate with extremely low annual rainfall except for the southwestern region of Asir, which is influenced by the Indian Ocean monsoons. Its irrigated land consists of about 16,200 square km; therefore, agriculture work occupies only 6.7% of the whole work force in the country [128, 131].

The livestock industry in Saudi Arabia is not large enough to meet the local demand, so the majority of livestock is imported. This makes Saudi Arabia one of the largest countries in the Middle East with respect to importing livestock from east African countries as well as Australia [132, 133]. Together with Yemen, it was the first country exposed to a RVF outbreak outside Africa [134]. It is important to study this unexpected outbreak in Saudi Arabia (also the first outbreak outside of Africa).

## ***Kenya***

Kenya is located in east Africa where it shares a border with five other countries and the Indian Ocean between Tanzania and Somalia. It has a total area of 580,367 square km and a population of about 47 million, where the majority is under 55 years of age. The urban population represents 26% of the total population[128]. The climate of the country varies between arid in the interior and tropical on the coast zone. It has different ecological zones including arid, semi-arid, humid, and semi-humid. Kenya has 15 rivers and 11 lakes [135] and around 48% of the country is agricultural land and 6% is forest. The irrigated land is about 1,030 square km. The majority of Kenyans (80%) are involved in agriculture, including livestock and pastoral activity. Agricultural activities offer jobs for 75% of the whole labour force in the country and contribute with 30% of the Kenyan national GDP [128].

Kenya has considerable livestock production (about 67,475,852 heads according to 2011 national census), but still imports beef and milk cows from South Africa. Kenya also has a large wildlife population (about 43,013,341 heads) [136]. In 1930, RVF was first recorded in Kenya and this was also the first recorded occurrence of RVF in the world [71]. Frequent outbreaks have occurred since then and two recent major RVF outbreaks in the country were reported in 1997-1998 and 2006-2007 [34, 137, 138]. This long history of the disease in Kenya has resulted in a time-series of RVF outbreaks that better facilitates RVF predictive modelling and risk mapping studies compared to other affected countries [139].

## **Study designs**

For papers 1 and 2, we conducted a systematic literature review to gather all knowledge of RVF in Sudan and Saudi Arabia. We compared how Sudan, a country with limited resources, and Saudi Arabia, a country with significant resources, confronted the disease. The main focus was on lessons learned of how Sudan and Saudi Arabia operationalized One Health when they attempted to implement different aspects of RVF outbreak control (Figure 4). For papers 4 and 5, in accordance with the guidelines for strengthening and reporting observational studies in epidemiology (STROBE), community based cross sectional surveys were conducted in both Sudan and Kenya. For paper 3, the sensitivity of seven selected ecological variables to RVF occurrence was assessed by generalized linear modelling (GLM). The GLM identified significant variables that could be used to develop a risk map of RVF occurrence in the studied counties in Kenya (Figure 5).

## **Study populations**

For papers 1 and 2, the data reviewed concerned the human and livestock populations that were affected by RVF in Sudan and Saudi Arabia. For papers 4 and 5, the human populations studied were local communities (235 households) in Managil, (Paper 4), which was exposed to highest number of cases during 2007 RVF outbreak in Gezira state, central Sudan. In Kenya, we selected Isiolo county in north-central Kenya (698 households) (Figure 5) which was exposed to RVF outbreaks in 2006-2007 and is inhabited by different community groups. For paper 3, the risk mapping model used density data of animal populations (FAO data) from the studied counties in Kenya (Figure 5).

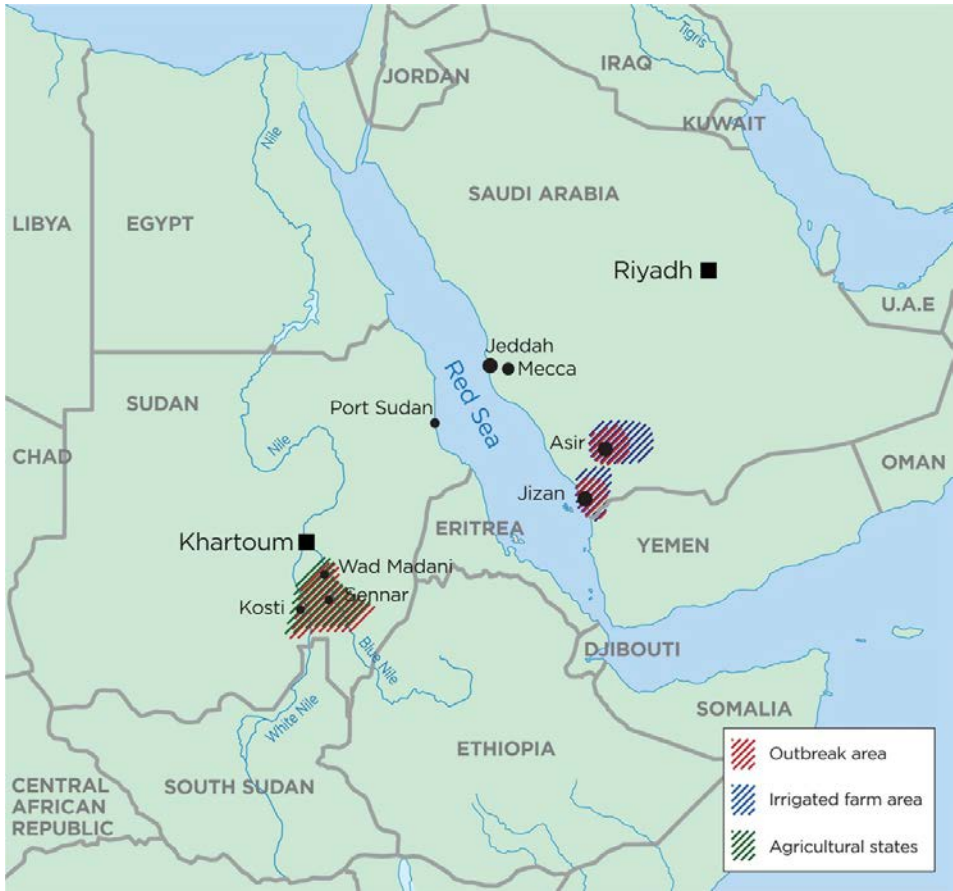


Figure 4 (from paper 2). Map of Sudan and Saudi Arabia. RVF outbreak areas are in red, irrigation and/or areas with seasonal water are in blue, and agricultural states are in green.

### Data collection and analysis

The data for papers 1 and 2 were extracted from literature, and a systematic literature review was conducted to analyse the data. For papers 4 and 5, a specifically designed One Health questionnaire (Appendix 1) was used to collect the data. The STATA software program was used to analyse the data. For paper 3, ecological variables such as vegetation seasonality and evapo-transpiration were collected from satellite data observation, and the animal densities and soil ratios were collected from FAO and Kenya soil surveys, respectively. The sensitivity of these variables were analysed by generalized linear modelling.

## Ethical considerations

Ethical clearance and participants' consents were granted from the appropriate authorities both in Sudan and Kenya for paper 4 and 5. The data were coded to assure the confidentiality of the studies participants.

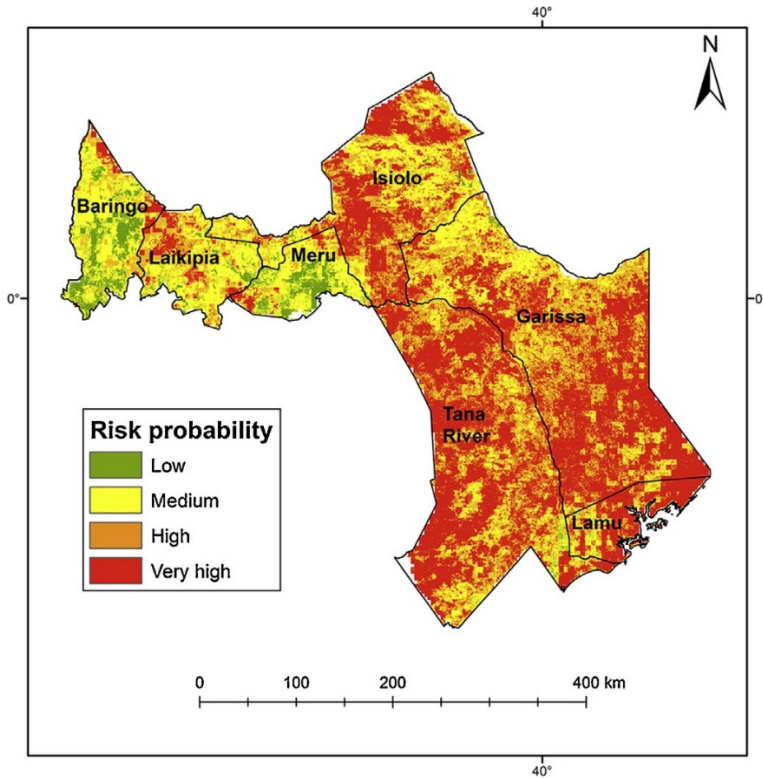


Figure 5 (from paper 3). Risk zone map for the study area based on an amalgamation of the variables that were found to be most significant in both GLM models ('animal density', 'small integral', and 'PC2\_ET').

# Results and Discussion

RVF emergence depends on humans, animals, vectors, and ecosystems. RVF outbreaks have occurred in different countries in Africa, most of them with limited economic resources, but RVF has also spread to Saudi Arabia, a country with extensive resources. For the purpose of discussing RVF emergence in developing and developed countries from a One Health perspective, I use our results from the RVF outbreaks in Sudan and Saudi Arabia. The results regarding the ecological factors necessary for RVF outbreaks are discussed in a global context. Finally, I summarize our results on how human behavior affects the severity of RVF outbreaks and how this knowledge can help countries and local communities to be better prepared for outbreaks.

## **RVF introduction and transmission before and during an outbreak**

The introduction of RVFV to Saudi Arabia in 2000 has been suggested to be connected to livestock imported from east Africa (Paper 2). After the outbreak, a phylogenetic study found a similarity between the Saudi Arabian RVFV strain and the RVFV strain that caused the 1997-98 outbreak in east Africa [140]. This geographical expansion through livestock trade was most likely amplified by the import of livestock to Saudi Arabia during Muslim visits to Makkah every year [133], where up to 15 million sheep, goats, and cattle are slaughtered every year. Most of these animals are imported from RVF endemic countries in east Africa. This points to the importance of regulations regarding livestock trade between endemic and non-endemic countries. Practical steps, such as vaccinating livestock in their country of origin, could help control the spread of RVFV. Likewise, serological tests should be provided not only in the country of import but also in the country of export.

The emergence of RVF in Sudan in 2007 is more obscure (Paper 1 and 2). However, a recent study of RVFV phylogeny revealed that the Sudan 2007 RVFV strains were genetically related with both the 1997-98 and the 2006-07 RVFV strains that caused the outbreaks in east Africa [80]. These data could be interpreted as indicating a multiple introduction to Sudan. Phylogenetic analysis of RVFV variants is important to understand the geographical source and distribution of the virus. In 2007, Sudan shared a border with Kenya in the south where the climate is tropical with a long rainy season conducive for mosquito habitat. Infected mosquitoes in the south of Sudan could potentially spread the virus to livestock population in this region because the population moves freely between the south and the

north of Sudan, which then could lead to infection of other livestock through mosquitoes. The cattle in Sudan are known to interact during the summer season when they meet at water sources located on the southern border of Sudan (now South Sudan). Mosquito vectors were studied and identified during the outbreak in Saudi Arabia, and proper control measures were applied [37]. However, the entomological survey should be expanded to other parts of the country in order to identify whether the mosquitoes managed to spread further to unaffected regions [133]. This should be considered a priority for the established program of RVF control in Saudi Arabia. Unfortunately, the role of mosquito vectors was not well studied in Sudan [141]. We suggest that entomological surveys in countries exposed to frequent arbovirus outbreaks should be undertaken (Paper 1). Lack of entomological data in different ecological zones weakens the efforts to control vector borne diseases in general. Knowledge about the density, types, and distribution of mosquitoes in a country is vital for the prevention and control of RVF [34]. To achieve this goal, we recommend a collaboration between governmental and research institutes in Sudan with possible technical support from the outside (Paper 1).

### **Ecology associated with RVF outbreak**

Part of the present thesis was to identify ecological factors that promote RVF outbreaks (Paper 3). In Saudi Arabia, the RVF outbreak occurred in dry areas with intermittent water sources, wadis (Paper 2). These wadis serve as an attractive habitat for mosquitoes as well as water sources for livestock and agriculture. In Senegal, a RVF outbreak was also associated with temporary water ponds in a semi-arid zone [142]. These type of outbreaks may not have the capacity to intensify as with outbreaks associated with irrigated, agricultural areas where large swarms of mosquitoes can spread the virus further. For example, in Sudan all the affected states were in agricultural areas similar to other agricultural areas that have been exposed to RVF outbreaks, such as the Ifakara project in Tanzania and highland in Madagascar [29] (Paper 1). To identify ecological variables determining RVF occurrence, we studied a region in Kenya that had experienced RVF outbreaks (Paper 3). Evapotranspiration, animal density, and the normalized vegetation differentiation index (NDVI) were significant ecological variables that explained RVF occurrence (Paper 3). Interestingly, in Kenya during the 2006-07 outbreak, human cases were only recorded in four districts, while livestock cases were reported from 26 of 29 districts [138]. A model based on only human cases would weaken the prevention and control strategy. In Sudan, the livestock cases were not reported and no data were available during the outbreak (Paper 1 and 2). This highlights the necessity of a One Health surveillance where the collaborative efforts of different sectors can detect the virus in the environment or livestock before causing an outbreak

in humans [143]. The evapotranspiration variable had good sensitivity for detecting wet land formed by heavy rains or floods that could be connected to mosquito vector habitats (Paper 3). The small integral of NDVI was found more useful than the large interval, particularly when it was used in a semi-arid zone where the vegetation variation was not as large compared to humid zones (Paper 3).

The three significant variables were used to develop a risk map for RVF in the selected region of Kenya (Figure 5 and Paper 3). The model managed to predict the areas that were affected by 2006-2007 RVF outbreak and were confirmed by data from other studies [144]. The model should be tested in countries other than Kenya to contribute to the improvement of early warning systems.

### **The role of the surveillance system in detecting RVF outbreak**

The first indication of a RVF breakout is usually when patients with hemorrhagic symptoms of unknown cause visit health care centers in the affected regions. This was the case both for Sudan and Saudi Arabia (Paper 1 and 2). Later it was shown that in Saudi Arabia there was extensive death and abortion among livestock [133], probably reflecting that herd immunity had not been established. In this case, RVF surveillance of livestock could have served as an early warning system. Sentinel livestock herds have been recognized as an important part of an early warning system to detect the circulation of zoonotic pathogens and provide time to allocate resources to the most exposed groups [145].

The livestock sentinel could include different animal types that are known to be sensitive to RVFV infection. Although a livestock sentinel project in Sudan was established a year before the 2007 RVF outbreak, this sentinel did not provide any warning (Paper 1). No or failed surveillance could have contributed to geographical expansion of the RVF outbreak in Sudan to unaffected states such as Gezira, Sennar, and Kassala. Unfortunately, there is no information about what could have caused that failure. Livestock sentinel surveillance could be an opportunity for One Health surveillance as the data collected on the livestock sentinel could be shared with the public health authority. This would require commitment and contribution from both the veterinary and public health authorities. The international support was instrumental in both Saudi Arabia and Sudan for robust analysis and confirmation of the outbreak (Paper 1 and 2). The technical support was also useful for the entomological survey in affected regions in Saudi Arabia, but this support was lacking in Sudan (Paper 2).



The first indications of a hemorrhagic fever disease outbreak in humans in affected regions could mean that different types of hemorrhagic fevers that circulates there, such as Crimean-Congo Hemorrhagic fever [146], Alkhurma hemorrhagic fever [147], or Dengue hemorrhagic fever [148] could be the cause, rather than RVFV. Before the diagnostic analysis identifies the pathogen, rigorous epidemiological investigations should be conducted to identify risk factors for disease and transmission. Consequently, preventive and control measures could then start before confirmation of the pathogen. Clearly, epidemiological studies focusing on risk factors can help prevent the severe consequences of RVF outbreaks especially if the outbreak occurs in new non-endemic regions where immediate access to relevant diagnostic techniques are limited.

### **Health system burden of a RVF outbreak**

The manner in which different countries and regions cope with an outbreak could largely depend on access to economic resources and available infrastructure. In Saudi Arabia, the RVF outbreak overwhelmed the health system for around seven months (Paper 2). During this time, 883 cases were reported and 124 cases died (i.e., case fatality rate of 14%). Of the reported cases, 75% developed liver failure, 41% acute renal failure, 20% hemorrhagic fever, 10% retinitis, and 4% encephalitis [60, 133, 149]. Clearly, the health system was challenged by this outbreak although Saudi Arabia had the resources to adequately deal with the outbreak (Paper 2). Interestingly, since the documentation of cases in Saudi Arabia was good, mild cases of RVF (cases exhibiting vomiting, nausea, abdominal pain, and diarrhea) were identified, improving the description of mild symptoms mentioned in previous outbreaks in Africa [149].

In the 2007 RVF outbreak in Sudan, 698 human cases were detected with 222 deaths (31.5% case fatality rate). The health system in Sudan was also overwhelmed by the RVF outbreak (Paper 1 and 2); there were 194 cases in the Gezira state alone and of these 60% had renal impairment of which 90% needed dialysis and 31% of those who experienced acute renal failure died [150]. This sudden increase in patients with severe symptoms added to the challenges facing the health system in a vast country like Sudan with limited resources.

Furthermore, the majority of the cases in Sudan occurred in remote rural areas, where health system was difficult to access. In such a context, health care based surveillance does not reflect the actual magnitude of the outbreak. This could explain the discrepancy between the estimated (75,000) [16] and the detected human cases (698) in Sudan. RVF is a disease that needs to be documented and discussed according to International Health Regulations.



That is, a discussion of a new framework for better surveillance with novel ideas that consider the limited resources in potential outbreak areas is vital to avoid further spread of RVFV.

Vertical transmission of RVFV from mother to child was first documented in two single case studies from Saudi Arabia and Sudan [151, 152]. In paper 1 we addressed the suspicion of miscarriage among pregnant women in rural areas in Sudan during the 2007 RVF outbreak. This suspicion was also discussed in a report from Mozambique in the 1980s [153]. In terms of comparative medicine, we hypothesized that this could occur in humans, since miscarriage in pregnant livestock is known to be associated with RVFV infection [154]. Recently, the association between RVFV infection and miscarriage in humans has been confirmed in Sudan [155]. Clearly, RVF affects both maternal and child health.

### **Effectiveness of actions against RVF outbreak**

In general, the measures taken by Saudi Arabian authorities has, as far as we know, managed to curb RVF outbreaks since the occurrence in 2000, except for sporadic cases in animals in 2008 and 2010 (Paper 2). New human cases were also registered in the neighboring region of Najran, but there was no information whether these cases were imported or contracted in this region [133]. Although the Saudi Arabian authorities applied rigorous interventions during and after the outbreak, the virus seems to have survived in the cryptic cycle mentioned above. The sustainable interventions include strengthening of veterinary services, such as animal RVF vaccinations [133], and regular screening of animals all over the country [156]. The human health system was also strengthened and more infection controls were applied to detect any new cases [157]. However, the Saudi Arabian sustainable approach of controlling RVF might not be possible for countries with limited resources. In Sudan, a new outbreak was reported in 2010 in Gezira, the state that was most affected during the 2007 RVF outbreak [80] (Paper 1). Unfortunately, this time the virus managed to cross the Blue Nile, which had been considered a barrier for the disease during the 2007 RVF outbreak. Very little information is available regarding the 2010 outbreak, but it seems as if RVF is expanding its geographical reach in Sudan.

### **Economic impact of RVF and One Health**

In our study of an agro-pastoralist community in Sudan, we showed that the 2007 RVF outbreak negatively affected household economy and food security (Paper 4). Most cases in Sudan involved young working age people (15-29 years), and this severely affected the rural economy. This pattern has been noted for other viral zoonotic outbreak, e.g., the 2009 Swine flu in South East Asia [158]. Many RVF cases were housewives, as in the outbreaks

in Kenya, and this might be attributable to their involvement with animal care at home [159].

Around half of the studied community in Sudan faced food insecurity and lack of income due to the outbreak (Paper 4). Livestock were the main source of food for 71% of the same community and 43% were involved in livestock trade as their source of income (Paper 4). This situation could have two implications: the affected people could be willing to be a part of future disease control measures or the affected people could be hesitant to be involved if their participation would result in stigma and negative economic consequences. Understanding this economic vulnerability is vital to target these communities for resilience programs after RVF outbreaks, and these programs could be stated in contingency plans. Restricting livestock trade would hit both the micro- and macro-economy. The lack of the regional or international assistance would complicate the crisis. In such a situation, local communities would be very hesitant to notify authorities about disease outbreaks if they suspected that their animals would be the target of an embargo. This is a big challenge for the early warning and notification of RVF. Presently, the local communities are not compensated for sick or dead animals. In paper 4, 60% of the study participants said they would not notify veterinary authorities. Actually, both local communities as well as national authorities may want to protect themselves from economic consequences. This hesitance would severely affect the mandate of the International Health Regulation which seeks openness and sharing of information when disease outbreaks occur that could cross country borders. The rural communities' health and lost livestock are coupled to the rights of protection of vulnerable and affected rural communities. This concern is similar to other ethical questions addressed during previous viral zoonoses outbreaks, such as severe acute respiratory syndrome (SARS) [160].

There are only a few studies on the economic impact of RVF outbreaks [21, 22] (Paper 2) and data are scarce about the cost of countermeasures for both humans and the livestock sector. The lack of integrated data makes it difficult to identify the most vulnerable groups within the livestock chain and makes it difficult to target and protect them if necessary. For instance, the budget for disease control could be established via a joint effort from multidisciplinary committees. Such approaches would guide the allocation of resources and would possibly save resources from unnecessary actions during the chaos of the outbreaks. It also provides an opportunity for cross-sectoral collaboration between environmental, veterinarian, social science, and health authorities. This collaboration would make it possible to determine if a One Health economic approach would benefit all domains.

## **The opportunities and challenges for involvement of the local community to control RVF**

We observed that agro-pastoralist communities lacked knowledge about the role of mosquitoes in disease transmission (Paper 4). In fact, 60% of the participants used mosquito bed nets, but 41% of the bed nets were not impregnated (Paper 4). Mosquito bites could be one explanation for the fact that RVF disease was not only restricted to occupational risk groups that had contact with livestock. The local communities' knowledge about the mosquito vectors could improve the local surveillance system. The community stated that the health authorities were the main sector for prevention and control of RVF. However, they ignored the interaction with sick or aborted livestock as a behavior that could accelerate the transmission. This also indicated that the local community was not considering the veterinary authorities important for controlling RVF at its animal origin. The community was not considering the One Health approach – i.e., the interconnection between animal, human, and environment. This lack of knowledge impedes the role of the local community to restrict RVF outbreaks.

Human behavior affects most parts of RVF emergence. If the livestock owners do not comply with suggested control measures, such as livestock movement restrictions and vaccination, no progress will be made. Thus, involvement of the agro-pastoralist communities is of utmost importance even if disease diagnostics and vaccination are technically developed and in place.

## **Risk communication with the public during RVF outbreak**

In Sudan, the rural community received information mainly from social networks such as friends and relatives (Paper 4). The consequences of receiving information from un-authenticated sources can lead to rumors that do not promote the best behavior. As the local communities did not rely on veterinarians with respect to outbreaks, the role of veterinarians has to be revised to help educate the public about zoonoses. Unless the information before and during outbreaks does not include socio-cultural aspects of the rural communities, anti-RVF campaigns will fail. Both health and veterinarian authorities should be part of the One Health education campaign. Social scientists has so far not clearly been part of the risk communication or behavioral change during or after the outbreaks in Sudan or in Saudi Arabia. In the future, the involvement of social science has been identified as a priority for the success of One Health [118].

It is important to understand the best channels of risk communication with the public, particularly during outbreaks [160]. In general, zoonotic disease

outbreaks have different components with respect to disease transmission, so a suitable model of risk communication should be used. A good example of such a framework model is “Seeking and processing information about the zoonotic disease risk: A proposed framework” [161]. This framework could be adapted to communicate with people during an RVF outbreak. The panic associated with outbreaks, as well as lack of resources, makes transparent and effective communication the best way to protect people until more active measures are in place [162].

### **Knowledge, attitudes, and practices influence RVF exposure**

In Kenya, the number of reported human cases and affected livestock herds varied between regions, but the reason for this variation has not been studied. One explanation could be socio-cultural differences affecting how the community reacts towards RVF. We studied 698 households in three different pastoralist or nomad communities in Kenya (Borana, Maasai, and Turkana) (Table 1 and Paper 5). They showed a different level of knowledge, attitudes, and practices towards RVF. For example, the Maasai had significantly higher knowledge of RVF ( $p < 0.01$ ) compared to the other two groups (Paper 5). This was not the case for the attitudes score that reflects their perceptions about sick livestock and humans: the Borana had a significantly higher score ( $p < 0.01$ ) compared to the other two groups (Paper 5). The practice score, which comprises the actions to avoid RVF, revealed that the Borana were also better compared to the other two communities (Paper 5).

Regarding the cultural practices known in medical literature to increase the risk of contracting RVF, the three communities acted differently (Table 1). For example, unlike the other two groups, the Maasai kept livestock in their home. However, slaughtering livestock inside the home was typical in the Turkana ( $p < 0.01$ ). In summary, the results indicated that being knowledgeable is not always a guarantee that you are less exposed to RVF, but rather having appropriate attitudes and practices relying on proven knowledge to prevent RVF is the best integrated approach for protection (Paper 5). As a result, we could explain why the Turkana group had the highest number of affected people ( $p < 0.05$ ) during the RVF outbreak in Kenya compared to the Maasai and the Borana (Paper 5). Compiled knowledge, attitudes, and practices were important tools that could disrupt the spread of disease among vulnerable communities, and this should be incorporated in prevention and control strategies.

Table 1: Cultural practices indicated by the community groups during the 2006/2007 RVF outbreak in Kenya

Community activity	Community groups		
	Turkana	Borana	Maasai
	(n = 175)	(n = 363)	(n = 160)
	%	%	%
Sheltering livestock inside home	49	11	96
Handling of sick livestock	85	72	82
Inspection slaughtered livestock	6	29	19
Consume raw meat	59	41	38

## **Methodological considerations for paper 4 and paper 5**

The One Health approach for studying RVF in relation to behavior was very useful for overcoming the challenges of disease sensitivity. RVF is a quite sensitive disease for rural communities, as it can result in devastating suffering and severe socio-economic challenges. The rural communities are not really interested in discussing RVF outbreaks because they want to avoid stigma. This ambivalence was managed by discussing the disease from different perspectives including livestock, humans, and the ecology. This approach made the rural community more comfortable as the focus was not on their main source of their livelihood – their livestock. Building trust with the local community and their leaders required many logistical and social efforts. A pilot study and pre-field visits were crucial to building the mutual trust that led to the high response rate of the study participants.

A cross sectional study is very useful for exploration and future planning, which fits with the overall aim of this project. It was also useful to collect deep knowledge about the topic from the perspective of the affected communities. This type of study and interaction can mediate the conditions needed to be explored by other social science studies [117]. This would not be possible without the proper planning and preparation of the study including a pilot study and pre-field visits to remote areas. This preparation was essential as it allowed the local community to have a sense of ownership of the study.

A possible limitation of any cross sectional study is recall bias. However, the well trained data collectors, the verification of the questions by the pilot study, the simple questions, and the uniqueness of the disease decreased the possible recall bias among the participants. The study also investigated current RVF knowledge in the community at the time of the study in order to plan for future RVF interventions.

## **Policy implications and recommendations**

This thesis described how knowledge of RVF from different research fields, such as epidemiology, public health, virology, medicine, veterinary medicine, entomology, and ecology, can be combined in a One Health perspective. The research on the One Health approach to RVF outbreaks in Sudan and Saudi Arabia guided our design of a unique One Health questionnaire that allowed for the simultaneous collection of data from the different fields relevant to RVF. Furthermore, ecological variables conducive for RVF outbreaks were determined. Thus, the results advocate for a One Health strategy when data are collected in order to have solid results that aim to confront RVF.

For spread of infectious diseases and particularly zoonoses such as RVF, socio-cultural behaviors play an important role in disease spread, but these behaviors have been less investigated in RVF research. We propose that understanding the influence of behavior and cultural differences is fundamental to improving prevention and control efforts among vulnerable groups where the disease occurs. We recommend that strategies to combat RVF should consider socio-cultural and behavioral differences among communities.

A successful policy to disrupt RVF outbreaks in the future will highly depend on considering the social, economic, and political factors associated with RVF as a transboundary disease governed by International Health Regulations. We recommend a better framework for regional and global collaboration to support countries overwhelmed by the disease and to help affected communities reach resilience against the devastating economic impact of RVF outbreaks. In addition, early warning systems for RVF could be better managed if we introduce more ecological variables that expand the predication models on a subscale level as these countries have different ecological zones.

The traditional surveillance has not been fully able to detect and identify RVFV circulation in remote areas. Our suggestion is to initiate a community-based surveillance strategy in order to enhance the early surveillance and notification in Sudan and in similar countries. However, the incentives must be there to motivate the local community involvement, for example, the compensation of sick and dead livestock. Furthermore, livestock sentinel surveillance and mosquito surveillance must be regarded as an opportunity to strengthen the national surveillance of many emerging zoonoses or arboviral diseases including RVF. This approach requires capacity building and leadership commitment. As a part of disease control policy, a well-tailored plan for communicating with the public should be developed according to the context of each country.

# Conclusions

In RVF naïve countries, such as Saudi Arabia, and in countries with limited resources, such as Sudan, an outbreak has severe consequences with a high ratio of infected livestock and an extra burden on the health system.

Differences between countries regarding further spread of RVF was mainly determined by better economic and infrastructure resources.

RVF has a negative economic impact for both the RVF-affected countries and their livestock trade partners in other countries.

Livestock density, evapotranspiration, and vegetation seasonality variables were highly relevant when determining the risk of a RVF outbreak, particularly in a sub-regional scale. Integration of these variables into local RVF early warning systems could improve the prediction of RVF outbreaks.

The One Health approach was a necessary framework to accomplish the socio-cultural and human behavioral studies in the agro-pastoralist communities affected by RVF.

RVF exposure could largely be determined by the socio-cultural and behavioral differences of different community groups. In general, more knowledge, better attitudes, and better practices could explain why certain community groups are less affected by a RVF outbreak. However, better RVF knowledge does not always translate to better practices.

The consequences of RVF outbreaks were more severe for local communities. Surveillance systems were not applied at these local communities to protect humans and livestock against RVF outbreaks.

Rural communities mainly receive information on RVF from social networks.

As local communities are the main stakeholders in the struggle against RVF, we suggest that One Health needs to be expanded in a bottom-up approach.



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