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The epidemiology of Rift Valley Fever in Yemen and the risk of re-introduction from the Horn of Africa.

L’épidémiologie de la fièvre de la vallée du Rift au Yemen et le risque de réintroduction à partir de la corne de l’Afrique.

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Dedication:

I dedicate the fruit of this humble effort

To my magnanimous

Teachers, Parents, wife Dr Samera Al-jarmouzi

My sweet children

Maryam, Rim, Abdulrahman and friends

Who always appreciate and pray for me to

Achieve higher goals in life.

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List of Abbreviations

- AGID: Agar Gel Immunodiffusion test
- AVHRR: Advance Very High Resolution Radiometer
- BHK: Baby Hamster Kidney
- BERMS: Basin Excess Rainfall Monitoring System
- CCD: Cold Cloud Duration
- CCHFV: Crimean-Congo Haemorrahgic Fever Virus
- CDC: Centre for Disease Control
- CIRAD: Centre de coopération Internationale en Recherche Agronomique pour le Développement - French research centre working with developing countries to tackle international agricultural and development issues
- DIVA: Differentiating Infected from Vaccinated Animals
- DNA: Deoxyribonucleic acid
- EFSA: European Food Safety Authority
- EID: Emerging and Infectious Diseases
- ELISA: Enzyme-Linked ImmunoSorbent Assay
- EMPRES: Emergency Prevention System for Transboundary Animal and Plants Pests and Diseases
- ENSO: El Niño – Southern Oscillation
- EU: European Union
- FAO: Food and Agricultural Organization
- FEWS : Famine Early Warning System
- FSAU: Food Security and Nutrition Analysis Unit –Somalia
- GDP: Gross Domestic Product
- GIEWS: Global Information and Early Warning System
- HIT: Heamagglutination Inhibition Test
- IAEA: International Atomic Energy Agency
- IFA : ImmunoFluorescent Assay
- IFAT: Indirect Immunofluorescent Antibody Test
- ILRI: International Livestock Research.Institute
- IRS: Indoor Residual Spraying
- ITCZ: Inter-Tropical Convergence Zone
- LACV : La Crosse Virus
- LSDV: Lumpy Skin Disease virus
- MAI: Ministry of Agriculture and Irrigation

- MRGI: Minority Right Group International
- NASA: National Aeronautics and Space Administration
- NAMRU3: U.S Naval Medical Research Unit 3
- NDVI: Normalized Derived Vegetation Index
- NICD: National Institute for Commicable Diseases South Africa
- NSm et NSs: Nonstructural proteins
- OIE: Office International des Epizooties
- OLR: Outgoing Longwave Radiation
- ORF: Open Reading Frame
- OVI: Onderstepoort Veterinary Institute (South Africa)
- OWOH: One World One Health
- PCA: Principal Component Analysis
- PDS: Participatory Disease Surveillance
- RNA: RiboNucleic Acid
- RSCZ: Red Sea Convergence Zone
- RSSD: Remote Sensing Satellite Data
- RT-PCR: Reverse- Transcription Polymerase Chain Reaction
- RVF: Rift Valley Fever
- RVFV: Rift Valley Fever Virus
- SNS: Smithburn Neutropic Strain
- SPS: Sanitary and Phyto-Sanitary standards
- SST: Sea Surface Temperatures
- TAU: Tropical Animal Units
- USA: United States of America
- VLPs: Virus-Like Particles
- VNT: Virus Neutralization Test
- WHO: World Health Organization
- WIO: Western equatorial Indian Ocean
- WNV : West Nile Virus
- WTO : World Trade Organization

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General Introduction

Rift Valley Fever (RVF) is one of the major vector-borne zoonosis which has historically solely affecting the African continent (Gerdes 2004). The first cases of RVF were reported in 1910 in the west of Kenya (Bird, Khristova et al. 2007) but the first RVF virus (RVFV) isolation was in 1930 near Naivasha Lake in the Great Rift Valley of the same country. It was following the observation of a wave of abortion in ewes (Daubney, Hudson et al. 1931), over a week period with the sudden death of around 4,700 lambs and ewes on farms of the area.

Veterinarians and other health personals, farmers, abattoir workers are the professionals at high risk of infection from direct contact with the infected animals. Thus, many historically outbreaks of RVF in Africa were initially detected because of illness among veterinarians and their assistants after they had performed necropsies on infected animals. The last one was in South Africa where several veterinarians staff and students were infected in 2008 after handling and performing necropsies on animals which were only later identified as infected with RVFV (Bird, Ksiazek et al. 2009)

Apart from human health aspects, the infection induces direct economical impacts through animal mortality and abortions (Clements, Pfeiffer et al. 2007). However, the indirect consequences are the most important, according to international sanitary agreement (SPS), because it leads into a very strict embargo on live animals or animal products exportation.

Due to the potential for the severe consequences during outbreaks, RVF is considered a major zoonotic threat. RVF is classified by the World Organization for Animal Health (OIE) as one of the threaten diseases of livestock trade, because RVFV is a pathogen with the potential to spread at international level (OIE 2008). In addition, it is considered a bio-weapon agent (Bouloy and Flick 2009).

RVF was considered an African disease for 70 years. Indeed, up to 2000 RVF was recorded only in Africa. RVF has been identified in most of the countries in Sub-Saharan Africa and Madagascar. But on 10th September 2000, the ministry of health of Saudi Arabia received report of a hemorrhagic fever in humans associated with animal deaths and waves of abortion in Tihama region. Most of human cases occurred in the floodplain of Wadis seasonal riverbeds that come from the foothill of Sarawat mountains, south of Jeddah and up to the border of Yemen with Saudi Arabia (Anonyme 2000) (Figure1).

Figure 1: RVF outbreak area in Yemen and Saudi Arabia border during 2000.

On September 15th, the Center of Disease Control (CDC) isolated RVFV (CDC 2000b). On the 19th, Yemen officially declared its first outbreak of RVF, five days after Saudi Arabia (Anonyme 2000). In October 2000, 316 human cases had been reported among which 253 (80%) were Saudi citizens and 63 (20%) were Yemeni citizens (Ahmad 2000).

The outbreak in Yemen started on the coast of Tihama (Az-Zuhrah district, Al–Hodeidah governorate) and led to about 21,000 aborted animal cases and 6,600 animal deaths between September 2000 and February 2001 (Al Qadasi 2002). On the human side, this outbreak led into about 1,080 human cases including 141 fatality cases. It started by a storm of abortions: up to 90% of pregnant animals were affected. Neither the veterinarians nor the human’s health care have had experience about RVF as it emerged for the first time in Yemen. In the beginning RVF was confused with malaria and dengue fever for which Tihama is an endemic zone (Davies 2000). The 2000 RVF outbreak is considered one of the most important epidemics in the modern history of Yemen’s animal diseases. Despite the quick reaction of the government and international organizations like the Food and Agriculture Organization (FAO), the OIE, the International Atomic Energy Agency (IAEA), the World Health Organization (WHO) and the U.S Naval Medical Research Unit 3 (NAMRU3), the socio-economic impact of RVF outbreak in Yemen was dramatic. It affected all the sectors of the society not only in the importing but also in the exporting countries. It took time to regain the trust of consumers of animal products.

Yemen is one of the main importers of livestock from the Horn of Africa. Twenty five to 40% of the total meat consumed annually is imported (ARD 2006). In addition to that Yemen has a unique geographical position in the Arabian Peninsula as it is situated at a very short distance from the Horn of Africa and has a long history of animal trade and human movements with it. Yemen is also a crossroad for animal trade heading towards the Arabian Peninsula and the Gulf countries. Since decades RVF has been circulating in Africa. Nevertheless, even if animal trade over the Red Sea has a long history, such an epizootic of abortions and deaths in animals had never been reported in Yemen before 2000. Indeed, a retrospective study conducted on 264 serums samples from the serum bank of 1996/97 collected from the outbreak area of Tihama Waides revealed that all samples were negative (Al Qadasi 2009). This led us to several scientific questions to be answered:

- Why was the epidemic located in the Tihama region on the western coast of Yemen and in Saudi Arabia and not on the Eastern coast of Yemen which is also an important route of entry of human and livestock from the Horn of Africa and Somalia in particular?
- What were the drivers –ecological, climatic, socio-economic, etc, - likely to explain the 2000 outbreak?
- Why did the disease start in Wadi Mawr and did not affect other *wadis* (valleys)?
- What was the socio-economic impact associated to this outbreak?
- Considering that the RVFV did not survive since 2000, what is the risk of re-introduction of RVF from the Horn of Africa through legal importation of livestock?
- What are the surveillance and control measures that should be taken building upon lessons learned from the 2000 outbreak?

There was a great need to conduct a research study to find out scientifically based answers to these questions and to give feedback to the Directory of livestock and veterinary quarantine as well as the Ministry of Agriculture in Yemen.

This thesis is divided into two main parts. The first part presents the state-of-the-art on RVF epidemiology (Chapter 1), the geographical context of Yemen (Chapter 2) and provides a review of the socio-economic aspects of RVF in relation to the Yemeni case (Chapter 3). In a second part, the results of the research studies are presented, namely a descriptive study of the RVF outbreak in Yemen in 2000-2001 (Chapter 4) and an analysis of the recent period (1999-2007) to assess potential environmental and socio-economic risk factors (Chapter 5). A risk assessment of the re-introduction of RVF from the Horn of Africa to Yemen via legal trade of small ruminants is also described (Chapter 6). Perspectives of the wholework are discussed (Chapter 7).

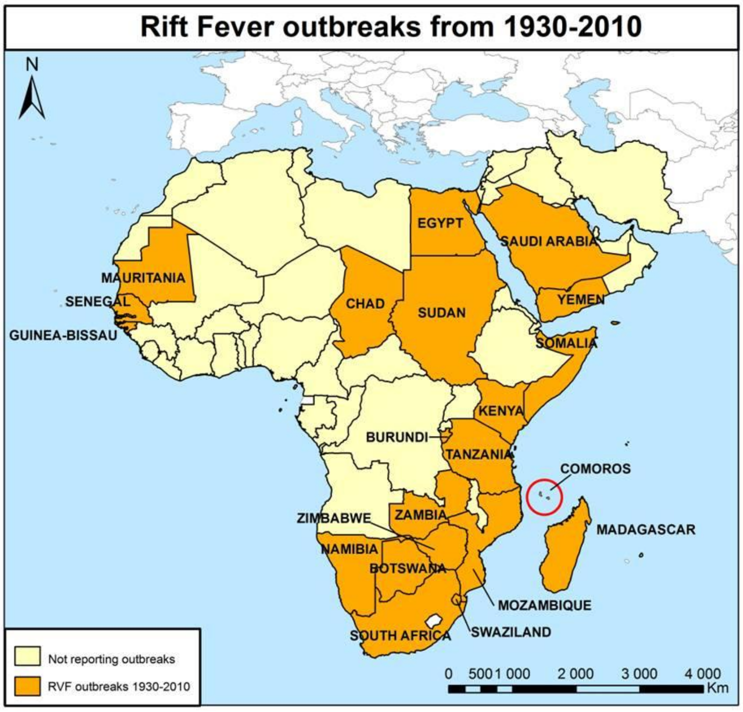
Part I: State-of-the-art

Chapter 1: Rift Valley Fever generalities

Rift Valley Fever is a vector borne zoonosis that is expanding its range in Africa and in the Arabic Peninsula. It has a heavy economic impact for the meat and diary producers when it occurs, *e.g*. high illness and mortality rate among affected livestock herds (Daubney, Hudson et al. 1931; WHO 2007). It causes abortion and high mortality among offspring of domestic ruminants during epizootics, and is responsible for hemorrhagic fever syndromes in humans (Meegan and Bailey 1988). During the severe outbreaks, an extensive number of human infections occur as well, leading to substantial healthcare challenges in terms of necessary resources (LaBeaud, Muchiri et al. 2008).

1 History of RVF and geographic distribution

The origin of RVF is the African continent. It primarily affected the Eastern part of the continent before reaching the Southern and then the Western part of Africa in the 1970s and late 1980s respectively (Saluzzo, Chartier et al. 1987). RVF spread outside of Africa in 2000 (Figure 2).



Countries	RVF outbreaks years
BOTSWANA	2010
BURUNDI	2007
CHAD	2001
COMORES	2007
EGYPT	1977, 1993, 2003
GAMBIA	1999, 2002
GUINEA-BISSAU	2005
KENYA	1930, 1931, 1961, 1962, 1997, 1998, 2002, 2006, 2007
MADAGASCAR	1979, 1990, 1991, 2008, 2009
MAURITANIA	1987, 1993, 1995, 2003
MOZAMBIQUE	1963
NAMIBIA	1985
SAUDI ARABIA	2000, 2001
SENEGAL	1987, 1993, 1995, 1999, 2001, 2004
SOMALIA	1997, 1998, 2007
SOUTH AFRICA	1950, 1951, 1953, 1955, 1956, 1970, 1975, 1981, 1991, 1999, 2008, 2009, 2010
SUDAN	1973, 1976, 1977, 2007
SWAZILAND	1978, 1990, 1991, 2008
TANZANIA	1997, 1998, 2007
YEMEN	2000, 2001
ZAMBIA	1973, 1974, 1978, 1985
ZIMBABWE	1955, 1957, 1969, 1978, 1998, 1999, 2001

Figure 2: Geographic distribution of Rift Valley Fever.

1.1 History of RVF in the Eastern and Southern part of Africa

In the Eastern part of Africa, the disease was first reported in 1910 in Western Kenya (Bird, Khristova et al. 2007). The virus was then first isolated in 1930 (Daubney, Hudson et al. 1931) in the same country. In Kenya, major outbreaks of the disease were recorded in ruminants in 1930-31, 1951-53,1961-63, 1968, 1978-79, and 1997-98 with smaller outbreaks during intervening years (Davies, Linthicum et al. 1985; Davies and Nunn 1998; Anyamba, Linthicum et al. 2001). Human cases were recorded in year 1931-32 (Findlay and Howard 1951). The very last severe outbreak occurred in 2006-2007 in the Horn of Africa, particularly affecting Kenya, Tanzania and Somalia (ProMED 2006; CDC 2007; Walter, Tabitha et al. 2007; WHO 2007.). The recorded increased activity of RVFV in the north-east of Kenya during the years 1961-1963 was associated to extensive flooding of the major watersheds (Davies 1975). The evidence showed that the epizootic virus activity had been associated with a period characterized by a more than average persistent rainfall and a raise of water level in the natural pans dambo (Davies, Linthicum et al. 1985; Davis and Martin 2006).

The disease was first recorded in South Africa in 1950-51 in humans who had performed a necropsy on an infected bull (Mundel and Gear 1951). During this period, it was estimated that 100,000 sheep died and 500,000 aborted due to RVFV. Cattle were also affected but to a lesser extent (Swanepoel, Coetzer et al. 2004). Outbreaks of lesser magnitude or sporadic isolations of the virus occurred in South Africa in 1952-53, 1955-59, 1969-71, 1974-75 and 1981 (McIntosh and Jupp 1981; Swanepoel, Coetzer et al. 2004). In 2008, clinical cases of RVF were recorded in buffaloes, leading to the death of 7 animals (WAHID.OIE 2008). The virus is still circulating in this country since the last outbreak was recorded in 2009 as well as some cases on sheep recorded in 2010 (WAHID OIE 2010). It affected 74 cattle and caused the death of 63 of them (WAHID.OIE 2009). Recently, human cases were reported in Free State Eastearn Cape and Norther Cape provinces. All the cases are farmers, veterinarians and farm workers (WHO 2010). According to National Institute for Commicable Disaeses (NICD), there were 111 confirmed cases and 9 deaths. Animal cases have been reported too (NICD South Africa 2010; ProMED 2010).

In Namibia, a severe outbreak affected sheep in 1955, and then a second major epidemic affected the region in 1974 and 1975 following periods of exceptionally heavy rain, some cases continuing to occur until 1976 (Coetzer and Barnard 1977). In Zambia outbreaks affecting mainly cattle happened in 1955-57, 1969-70, 1973-74, 1978 and 1985 (Christe 1969; Swanepoel and Coetzer 1994). In 1978, Zimbabwe was also affected by a major epidemic which was estimated to have caused 60,000 abortions and nearly 10,000 deaths in cattle (Swanepoel and Coetzer 1994). In 1979, it was the first isolation of RVFV outside the main continent of Africa: the virus was found from a mosquito pool collected in a forested area of Madagascar island (Morvan, Rollin et al. 1992).

Late 2006 and up to April 2007, during the El-Niño phenomena severe outbreaks occurred in the Horn of Africa affecting Kenya and then extending to Somalia and Tanzania (WHO 2007.). The disease spreaded into the Indian Ocean: one human case of RVF was detected in the Comoro island and some animal samples were found sero- positive in Mayotte (Sissoko, Giry et al. 2009). This expansion was suspected to be related to the livestock trade from Tanzania, as it is one of the main exporter of livestock to the islands (De Deken, Martin et al. 2007). However, in 2007, some IgM sero positive animal samples were recorded in Somalia (Saeed 2008) and IgG recorded in Somaliland and Puntaland (Medina and Tempias 2008). In 2008 RVF outbreaks affected Madagascar and some cases were reported in South Africa (WAHID.OIE 2008; WHO 2008). The same year, for the first time some human cases were recorded in Mayotte Island within the Comoros Archipelago located between the Horn of Africa and Madagascar (Sissoko, Giry et al. 2009).

1.2 History of RVF in the Northern and Western parts of Africa

In 1973, RVF was reported for the first time in North Africa. The virus was isolated and identified for the first time in Sudan (1976-1977), in Kosti-District, about 200 km south of Khartoum, in the White Nile province. The disease was reported in sheep, goats and cattle and the morbidity rate was estimated to be close to 100% (Eisa and Obeid 1977 b). The mortality rate was very high in young lambs (96%) and in adult sheep (70%), high in goats (50%) and medium in calves (20%) (Peters and Anderson 1981). During 1977 and 1978, a severe epidemic occurred in Egypt along the Nile Delta causing an unprecedented number of infections, abortions and deaths in sheep and cattle as well as some losses in water buffaloes and camels (Peters and Anderson 1981). This outbreak is remarkable in the history of RVF because it caused many human cases and was located near the irrigation scheme. This emergence outside sub-Saharan Africa was linked to previous outbreaks in neighboring Sudan in 1976. A second severe outbreak occurred in 1993 (Arthur, el-Sharkawy et al. 1993) and a third in 1997 (Abd El-Rahim, El-Hakim et al. 1999). During the last outbreak in Sudan in 2008, both human and animals cases were reported (WAHID.OIE 2008).

In West Africa the first outbreak was reported in 1987 in the south east of Mauritania and the Senegal River Valley (Jouan, Le Guenno et al. 1988; Digoutte and Peters 1989). Several studies showed that RVFV had circulated in many African countries: Burkina Faso, Botswana (Kokernot and Szlamp 1965 b), Angola, Central Africa (Georges, Wahid et al. 1983), Niger (Akakpo, Saluzzo et al. 1991), Chad (Ringot.D, Durand.J.P et al. 2004), Cameroon and Madagascar, where the last outbreak has been recorded in 2008 (Morvan, Lesbordes et al. 1992; WAHID.OIE 2008). In 2010 RVF was reported in Botswana for the first time (ProMED 2010; WAHAD OIE 2010).

2 Causative agent of RVF

Rift Valley Fever virus is a member of the Bunyaviridae family and the Phlebovirus genus (Table 1). It was first isolated in Kenya in 1930 (Daubney, Hudson et al. 1931) from an infected newborn lamb as part of an investigation around a large epizootic of the disease causing abortion and high mortality in sheep. Large epizootics in various areas of sub-Saharan Africa have been noted since that time and clinically compatible outbreaks have been retrospectively identified as far back as 1912 (Eddy and Peters 1980).

Genus	Main Group	Notable Virus Members	Geographic Distribution	Principal Arthropod Vector	Disease
Phlebovirus	Sandfly fever group		America, Africa, Asia Europe	Mosquitoes, Phlebotomine flies, Mosquitoes	Human
		Chandiru	South America		Human
		Punta Toro	North and South America	Phlebotomine flies	Human
		Rift valley Fever	Africa	Mosquitoes (Aedes, Culex,)	Human Cattle
		Sandfly fever Naples	Europe, Africa, Asia	Phlebotomine flies	Human
		Toscana	Europe	Phlebotomine flies	Human
		Sandfly fever Sicilian	Europe, Africa, Asia	Phlebotomine flies	Human
		Charges	North America	Phlebotomine flies. Mosquitoes	Human
	Uukuniemi Group		World wide	Ticks	Seabirds
		Uukuniemi	Europe	Ticks	Seabirds

Table 1: The different genera of family Bunyaviridae, vectors and geographic distribution. Source: (Kanipe and Howley 2009)

3 Affected species

Rift Valley Fever Virus affects a wide range of vertebrates, but the clinical disease is limited to domestic (cattle, sheep, goat, camels) and sometimes wild ruminants (Davies and Karstad 1981; Gerdes 2004; OIE 2008). In Kenya it affects wildlife which may act as reservoir: African buffalo (*Syncerus caffer*), elephante (*Loxodonta Africana)*, warthogs (*Phacochoerus aethiopicus*) (Lefèvre, Blancou et al. 2003), black rhino *(Diceros bicornis*), zebra (*Equus burchlli*), Thompson gazelle (*Gazelle thompsonii*), kudu (*Tragelaphus strepsiceros*), impala (*Aepyceros melampus*), and waterbuck (*Kobus ellipsiprymnus)* (Evans, Gakyua et al. 2008). In South Africa evidence of RVFV infection was shown in lions (*Panthera Leo*), cheetahs (*Acinonyx jubatus*), Africa wild dogs (*Lycaon pictus*) and Jackals (*Canis spp*).

The virus was also detected in Springbok (Antidorcas marsupuialis) and damaliscus (*Damaliscus ablifrons*). RVF antibodies were found in different species including *Mastomys erythroleucus*, *Aethomys namaquensis* and *Arvicanthus niloticus* (Gonzalez, McCormick et al. 1983; Niklasson and Gargan 1985; Pretorius, Oelofsen et al. 1997; Diop, Thiongane et al. 2000). The RVFV was also isolated from two bat species (*Microperopus pusillus* and *Hipposideros abae*) in the Republic of Guinea (Boiro, Konstaninov et al. 1987). *Miniopterus scheriberibersii* and *Ptesicus capensis* are known to be susceptible to experimentaly induced RVFV infection (Oelofsen and Van der Ryst 1999). However, the role of chiropterans in natural cycle/history of RVFV is controversial (Chevalier, Martin et al. 2008).

4 Vectors

Rift Valley Fever virus has been isolated from more than 30 species of mosquitoes from at least 6 genera: *Aedes, Culex, Anopheles, Eretmapodites, Mansonia* and *Coquillettidia* (Meegan, Baily et al. 1989). Floodwater mosquitoes belonging to the *Aedes spp* genus (subgenera *Aedimorphus* and *Neommelaniconion*) which emerge in enormous numbers in floodplains and other habitats where they oviposit, are the primary vectors while *Culex spp*. and others genus constitute the secondary vectors (Linthicum, Kaburia et al. 1985). The hatching dynamic of such floodwater *Aedes* mosquitoes depends on the rainfall pattern. *Aedes* females lay eggs in pond mud. Although these eggs become desiccated when ponds dry up, they remain viable for several years or even decades in the dry mud. As demonstrated through *Aedes mcintoshi* in Kenya, the ovaries and ovarian ducts in a mosquito infected with RVF can transmit the virus to the nascent eggs. When infected via transovarial transmission, eggs allow the virus to persist in the field during dry and/or inter-epizootic periods. Eggs need to be flooded to hatch. Heavy rainfall results in a massive hatching episode and, consequently, the development of a large first generation of vector population. A proportion of these mosquitoes may be infected with the RVFV and seed the virus in ruminants that are exposed when they drink from or feed close to the water pools. Whether these infections generate into epizootics depends upon the water pools remaining for four to six weeks or more, thus enabling subsequent generations of *Aedes* vector mosquitoes (Figure 3) to breed rapidly and create the huge mosquito populations seen during RVF epizootic/epidemic periods (Fontenille, Traore-Lamizana et al. 1998). Then, once infection has been amplified in livestock, secondary vectors such as *Culex spp*. (Figure 4), which breed in permanent pools of water, can become involved in the transmission of the virus.

Figure 3: *Aedes vexans* male showing distictive antennae
(source http://www.ent.iastate.edu/imagegal/diptera/culicidae/Ae-vex-M.html)

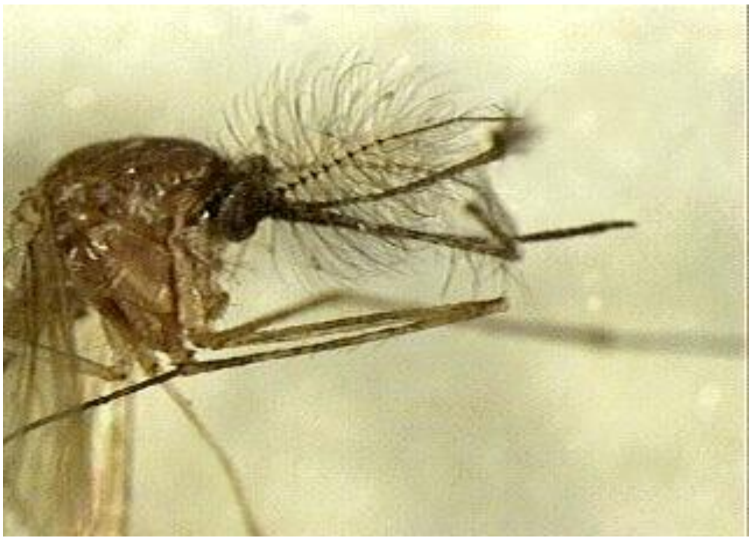


Figure 4 *Culex pipiens* male (source: //www.ent.iastate.edu/imagegal/diptera/culicidae/CxpipM.html)

In East and South Africa, the main vectors are *Ae. cumminisii*, *Ae. circumluteolus* and *Ae. mcintoshi*.(McIntosh, Jupp et al. 1980; Linthicum, Davis et al. 1985; Sang, Kioko et al. 2010)

In Senegal, the main endemic vectors are suspected to be floodwater *Aedes* which breed in temporary ponds such as *Aedes dalzieli*, *Ae.vexans arabiensis* and *Ae. ochraceus* (Chevalier, Lancelot et al. 2005). Moreover, secondary vectors such as *Culex poicilipes* which breed in semi permanent or permanent ponds could be implicated in RVF outbreaks (Mondet, Diaïté et al. 2005).

InSaudi Arabia, *Ae. vexans arabiensis* and *Cx. tritaeniorhynchus* (Table 2) have been implicated as main vectors during the RFV outbreaks in 2000 (Jupp, Kemp et al. 2002; Miller, Godsey et al. 2002).

Countries	Species
Egypt	*Culex pipiens* *Aedes caspius*
Saudi Arabia	*Aedes vexans arabiensis* *Culex tritaeniorhychus*
Senegal	*Aedes vexans arabiensis* *Aedes ochraceus* *Culex poicilipes*
Kenya	*Aedes cumminsii* *Aedes circumluteolus* *Aedes m intoshi*
South Africa	*Aedes mcintoshi* *Aedes unidentatus* *Aedes dentatus* *Culex zombaensis*

Table 2: Main RVF vectors in Africa and Saudi Arabia

5 Disease in humans and animals

5.1 In humans

Human death following natural infection was first recorded during the epidemic in 1975 in South Africa when seven patients died of encephalitis and hemorrhagic fever associated to necrotic hepatitis (Gear 1977; McIntosh, Russell et al. 1980).

In humans RVF infections are usually unapparent or associated to moderate to severe nonfatal influenza like illness (Swanepoel, Struthers et al. 1986) (Figure 5). Few patients may develop ocular lesion, encephalitis of a severe hepatic disease with hemorrhagic manifestation leading generally to death. Human infections may result from direct contact with tissue and body fluid of viraemic ruminants (slaughtering, abortion products) in the case of laboratory workers for example (Meegan 1981). Thus, particular care should be taken when working with infected animals, when performing post-mortem examination (WHO 1999) or manipulating the disposable of carcasses or foetuses. The virus may infect humans through inoculation, for example via a wound from an infected knife, through broken skin or through inhalation of aerosol produced during the slaughter of an infected animal. There is some evidence that humans may also become infected with RVF by ingesting the unpasteurized or uncooked milk of an infected animal (WHO 2007). Human infection has also resulted from the bite of an infected mosquito, most commonly the *Aedes*. Human to human transmission of RVF has not been documented (WHO 2007).

Figure 5 Human infected with RVFV during the 2000 outbreak in Tihama, Yemen

In some countries (Egypt, Sudan) RVF has been recognized in human before livestock which may suffer only unapparent infection (OIE 2000; WHO 2008).

5.2 In animals

Rift Valley Fever has a short incubation period: 12-36 hours in lamb. A biphasic fever of up to 41°C may develop, and the fever remains high until shortly before death (OIE 2000). Affected animals are listless, disinclined to move or feed, and may show enlarged lymph nodes and evidence of abdominal pain. Lamb rarely survives longer than 36 hours after the onset signs of illness. Animals older than 2 weeks may die preacutely, acutely or may develop an unapparent infection. Some animals may regurgitate ingesta and may show meleana or bloody foul-smelling diarrhea (Erasmus and Coetze 1981), but they usually represent less than 10% of the cases (OIE 2008). The hepatic lesions of RVF are very similar in all species and vary mainly with the age of the infected individual (Coetzer and Ishak 1982). In adult sheep, the lesions are less severe and pinpoint reddish to greyish with white necrotic foci distributed throughout the parenchyma. Haemorrhage and oedema of the wall of the gallbladder are common. In animals the spleen and peripheral lymph nodes are enlarged, oedematous and may have petechiae.

Sheep younger than one month old are highly susceptible to RVFV infection with a mortality rate reaching approximately 90 to 100%. The incubation period is 12-24 hours and the infection associated to a high temperature reaching up to 41 to 42 °C and showing rapid progress to death in 24 to 72 hours (Erasmus and Coetze 1981; Bird, Khristova et al. 2007; Bird, Ksiazek et al. 2009). The adult sheep, less susceptible than the lambs, show a mortality rate of 10 to 30%. The proportion of abortions could be very high up to 90 to 100%, which gives the characteristic storm of abortion associated to RVF epizootics (Swanepoel, Coetzer et al. 2004). The necrosis of fetus, placenta cotyledons and caruncles associated with abortion are characteristic of RVF (Coetzer 1977) (Figure 6). In adult sheep, the incubation period is 24 to 72 hours followed by a generalized febrile response, lethargy, hematemesis, hematochezia and nasal discharge (Coetzer 1977; Erasmus and Coetze 1981). Cattle calves from less than 1 month old are susceptible to lethal RFV infections with an estimatited mortality rate ranging from 10 to 70% (Coetzer 1977; Erasmus and Coetze 1981). The adult bovines are more resistant to lethal infection than sheep with a fatality rate of approximately 5% to10%.(OIE 2000).

In cattle, the main symptom is a high rise of fever for 1 to 4 days in duration along with in-apparent lethargy, hematochezia associated to epistaxis (Coackley, Pini et al. 1967) and reduced milk yield in lactating cows (Coackley, Pini et al. 1967; Erasmus and Coetze 1981). The severe infection of RVFV in cattle has similar characteristic than in sheep.

Figure 6: Aborted fetus during the last outbreak in South Africa (Source: Dr Born Reininghaus)

Goats are highly susceptible to the infection but more refractory to severe or lethal disease than sheep (Nabeth, Kane et al. 2001) In camels RVF was confirmed in 1961 in northern Kenya (Scott, Coackley et al. 1963). Moreover it was reported with high prevalence in the years 1977-1978 in during the Egypt epizootic (Bird, Ksiazek et al. 2009). The resistant genotypes of the indigenous African cattle and sheep often show no clinical sign of the illness with a brief period of viraemia (Davies and Martin 2003). Microscopically, hepatic necrosis is the most obvious lesion of RVF in both animals and humans. In adult animals hepatic necrosis is less diffuse in sheep icterus, and is more common than in lambs (Swanepoel and Coetzer 1994). RVF should be suspected when unusually heavy rains are followed by the occurrence of abortions together with a fatal disease marked by necrosis and hemorrhage in the liver that particularly affects lamb, kid and calves concurrent with the occurrence of an influenza illness in farm workers and people handling raw meat (OIE 2008).

6 Diagnosis and prevention of RVF

6.1 Identification of the agent

The virus can be isolated from blood, preferably collected with an anticoagulant during the febrile stage of the disease or from liver, spleen and brain tissue of the animals that have died. It can also be isolated from the organs of aborted fetuses. Primary isolation is usually made on cell cultures of various types such as kidney epithelial cells of the African Green Monkey, baby hamster kidney cells (BHK-21), or sheep or cattle primary cells.

Alternatively hamsters, adult or suckling mice, embryonated chicken eggs or 2-day-old lamb may be used for primary virus isolation. The RVFV can be identified by conventional PCR targeted on the NSs gene or by real-time PCR based on different genes such as NSs, Gn, N, et L, respectively (Jupp, Grobbelaar et al. 2000; Garcia, Crance et al. 2001; Sall, Thonnon et al. 2001; Naslund, Lagerqvist et al. 2008; OIE 2008; Peyrefitte, Boubis et al. 2008; Le Roux, Kubo et al. 2009).

Another rapid technique of diagnosis can also be achieved by using the supernatant of homogenised samples as an antigen in a virus neutralisation test (VNT), immunofluorescent staining of impression smears of liver, spleen, brain or infected cell cultures or by the demonstration of the virus in serum, taken during the febrile stage of the doses, by enzyme immunoassay or immunodiffusion, techniques that are nowadays not so used anymore.

The presence of characteristic histopathological lesions in the liver assists in the diagnosis.

The classical methods for the detection of antibodies of RVF are Heamagglutination inhibition test (HIT), Complement fixation test, Indirect Immunofluorescent Antibody Test (IFAT), Virus Neutralisation Test (VNT) and Enzyme Linked ImmunoSorbent Assay (ELISA).

Infected animals develop specific antibodies that may become demonstrable by VNT as early as 3 days following the infection and after 6-7 days by ELISA and HIT (Fig7).

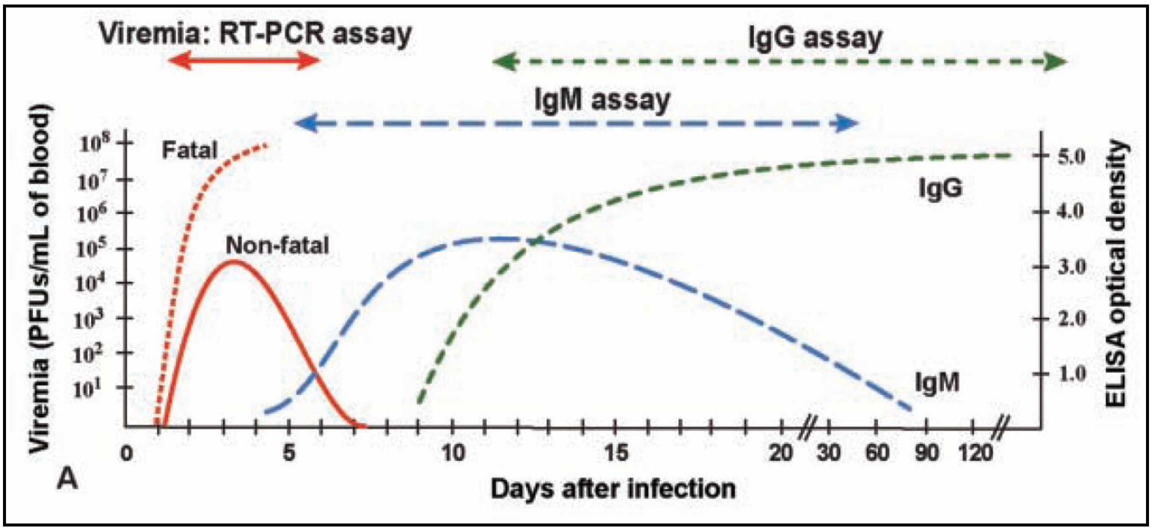


Figure 7: Methods of diagnosis of RVF. Source: (Bird, Ksiazek et al. 2009)

The delay of diagnosis of RVF associated with traditional virus isolation and identification techniques may represent a significant problem for the regulatory healthcare authorities, especially outside its traditional geographical confines or limits (Paweska, Brut et al. 2005). Accurate diagnosis of RVF can be achieved when serological tests are used in combination with clinical observation and epidemiological history (Swanepoel, Struthers et al. 1986). These techniques induce health risk to laboratory personal (Smithburn, Mahaffy et al. 1949).

The ELISA (IgG and IgM) test is found to be a highly accurate diagnostic tool in the disease surveillance and control program for import and export, veterinary certification and for monitoring immune response in vaccinated animals. This test may be useful in detecting antibodies in RVF-infected sera in the field because it is rapid, sensitive, and specific (Niklasson and Gargan 1985). Different kits are available base on the whole antigens (Paweska, Mortimer et al. 2005) ,or the N protein (Paweska, Van Vuren et al. 2007; Van Vuren, Potgieter et al. 2007; Paweska, Van vuren et al. 2008).

The HIT can be used with the great confidence in nonendemic areas (OIE 2008) although it is not commonly used anymore in the case of outbreaks.

6.2 Prevention and control

6.2.1 Vaccines

The spread of RVFV may be prevented by effective vaccination of animals**.** Several kinds of vaccines exist for livestock. But the real threat caused by RVFV is that there is currently no effective licensed vaccine for veterinary use in North America or Europe (Bouloy and Flick 2009; Ikegamia and Makino 2009). The development of a live attenuated vaccine which rapidly induces protective immunity without needing a series of boost administrations is important. For the human use in 1970 a formalin-inactivated product, safe and immunogenic was developed (designated as TSI_GSD200). The use of this vaccine was targeted to laboratory workers and other occupation risk RVFV exposed persons and military personnel and not commercially available (Kark, Aynor et al. 1982; Pittman, Liu et al. 1999)

- Available vaccines for livestock (Table 3)

An inactivated vaccine is available commercialy from Onderstepoort Biological Products Ltd. (South Africa). It is expensive to produce and requires multiple inoculations and regular boosters to induce and maintain immunity (Barnard 1979; Bouloy and Flick 2009). This vaccine reduces the abortion of ewes and the mortality of newborn lambs and induces immunity in cattle (Barnard and Botha 1977).

The Smithburn vaccine is attenuated. A single dose of live-attenuated Smithburn strain of RVFV is immunogenic and efficient in adult sheep and cattle but also causes abortion or has a teratologic effect in fetuses on up to 25% of pregnant animals (Morvan, Rollin et al. 1992; Botros, Omar et al. 2006). Vaccination should not be recommended when epizootic virus activity has been confirmed (Davies and Martin 2003). Due to its potential residual pathogenic effect, this vaccine is likely to be unsuitable for use in regions outside of the endemic zone of RVFV activity (Bouloy and Flick 2009).

Rift Valley Fever Vaccines currently produced

Available Vaccine				
Vaccine	**Strain**	**Advantages**	**Disadvantages**	**References**
Inactived (OBP,VSVRI)	Pathogenic field strain	Safe in pregnant animals. Can be used during outbreak	short term immunity Multiple vaccine required Risk of Handling virulent strain during production Colostral immunity present but poor. Sheep better protected than cattle 100x more antigen required than for live attenuated. Longer production lead time	Barnard.1979, Bouloy and Flick 2009, Barnard and Botha 1977
Live attenuated (OBP,KEVEVAPI)	Smithburn	Highly immunogenic Single dose Good immunity within 12 days Effective and easy production Safer producation. Large batches: > 4m doses	Potential residual virulence Teratogenic for fœtus Potential risk of reversion to virulence Not advisable for use during outbreaks Theoretical possiblity of transmission by mosquitoes	Morvan,et al.,1992, Botros, et al.,2006,Davies and Martin.2003, Bird et al.,2009

Table 3: Rift Valley Fever Vaccines currently produced

- Vaccines under development (Table 4)

A highly safe attenuated vaccine MP-12 was derived by mutagenesis of RVFV (Caplen, Peters et al. 1985; Takehara, Min et al. 1989; Vialat, Muller et al. 1997). A signal dose of this vaccine was proven to be safe and efficient in sheep and cattle. Providing protection from virulent virus challenge it can be used in not endemic countries. MP 12 has been tested for its potential as both a veterinary and human vaccine for RVFV. It induces an immunization of ewes at 70-100 days of pregnancy without fetus abnormality (Morrill, Carpenter et al. 1991)

Two alternative live-attenuated RVF vaccines are being developed: The clone 13(Muller, Saluzzo et al. 1995): This vaccine was recently challenged against pregnant sheep proved that it is safe in different stages of pregnancy (Dungu, Louw et al. 2010). In addition it was found that clone 13 would not be effeiciently transmitted by mosquito vectors (Moutailler, Krida et al. 2010) . Another reassotant R566 (Bouloy and Flick 2009) which is the natural variants of RVF have been produced as well (Moussa, Abdel-Wahab et al. 1986; Bird, Albariño et al. 2008)

Other vaccine types are under development:

Recombination poxviruses with Lumpy Skin Disease virus (rLSDV): mice vaccinated with 1x107 pfu recombinant LSDV develop neutralizing antibodies and are fully protected from a 100 LD50 lethal viral challen (Wallace and Viljoen 2005),these data have been validated in sheep as well (Wallace, Ellis et al. 2006).

- Virus like particles (VLPs): they are non-infectious particles since they assemble without incorporating genetic material. They may be more immunogenic than recombinant proteins as they present a more natural format that maintains conformational epitopes that can induce neutralizing antibodies (Grgacic and Anderson 2006; Habjan, Pichlmair et al. 2009; Näslund, Lagerqvist et al. 2009) The baculovirus expression system has the potential to produce a large amount of VLPs that may be used both for fundamental research on virus morphology and entry in cells as well as vaccine (Liu, Celma et al. 2008)
- DNA vaccines: DNA-based vaccine platforms have been used to induce immunity against RVFV (Spik, Shurtleff et al. 2006), Also, it has been found that two single doses of pCMV-4 resulted in full protection against RVFV in mice but the production costs is usually high enough to hamper the widespread use of DNA vaccine in veterinary speices (Lorenzo, Martin-Folgar et al. 2010) .
- Recombinant viruses such as the recombinant Newcastle disease NDV vaccine, producing the protein Gn of RVF. It was found that the calves immunized via intramuscular or intranasal route were protected with two shots of vaccination (Kortekaas, Dekker et al. 2010). Also a sindbis virus replicon has been developed and it’s provided 100% protection against lethal RVFV challenge by either intra-peritoneal or intranasal route.This vaccine elicits a RVFV neutralizing antibody response in vaccinated sheep (Heise, Whitmore et al. 2009) .

- Reverse genetics: these potential candidate vaccines have a NSs entirely deleted (Bird, Albarino et al. 2008; Bouloy and Flick 2009; Habjan, Pichlmair et al. 2009)These gene deletions allow the serological differentiation between naturally infected animals and vaccinated animals based on NSs.

Vaccines under development				
Vaccine	**Strain**	**Advantages**	**Disadvantages**	**References**
Live attenuated	MP12	Effective and good protective immunity	Teratoggenic for fœtus	Caplen, et al., 1985, Takehara,et al.,1989,Viallat,et all.,1997
Live natural mutant	Clone 13	-Easy and safe to produce. -Better safety than Smithburn in most species -Good protective immunity in sheep and cattle. -Safe in pregnant animals. -Safe in outbreak. -Produced as standard freez-dried live vaccine. -Safe effective and easy to produce. -Possible DIVA (NSs ELISA?)	Abortion in early pregnancy Not available commercially Not yet registered vaccine No large scale field data yet available, although extensive analytical data generated	Muller,et all.,1995,Dungu,etal.,2010
Avirulent (lab generted) reassortant	R566	Safer due to deletions in all 3 segements may never reassort	Never tested in target animals More stringent regulatory requirements for registration (?)	Bouloy and Flick 2009, Moussa, et al., 2008
Recombinant Lumpy skin virus expressing RVF	LDS Neethling strain expressing RVF glycoproteins	-Dual vaccine -Safe in all animals -DIVA. Differentiating Infected from Vaccinated Animals -Long shelf life (LSD) -More thermo-tolerant than others -Efficacy shown in animal trials.	Only proof of concept to date. Currently grown in primary celles. GMO regulation (?)	Wallace, et al., 2006, Wallace and Viljoen 2005.
Virus-like particles (VLPS)	Non infectious particles without in corporating genetic material	-More immunogenic than recombinant. -More natural format . -Induce neutralizing antibodies	Not available commercially	Grgacic and Anderson, 2006,Habjan, et al.,2009,Naslund,et al.,2009, Liu,et al.,2009.
DNA	DNA-based vaccine	Two single doses PCMV-4 produce full protection in mice	High cost of the producation	Spik, et al. 2006, Lorenzo, Martin-Flogar.et a., 2010
Recombinant Newcastle disease vaccine NDV	Recombinant Newcastle vaccine producing the protein Gn of RVF	Two shots immunized calves via I/M or I/N routs.	High cost of the producation	Kortekaas, Dekker et al 2010, Heise, Whitmore.et al 2009.
Reverse genetics vaccine	Entirely NSs delited	-Potential candidate vaccine. -Allow the serological differentiation between naturally infected animals and vaccinated animal based on NSs	Not available comercially	Bouloy and Flick. 2009, Habjan,et al.,2009

Table 4: Rift Valley Fever Vaccines under development

The safer candidate vaccines have been obtained based on naturally, chemically or genetically attenuated virus that could protect lambs or laboratory rodents from experimental virus challenge. The development of a safe and effective RVFV vaccine is required to protect humans from RVFV during the outbreaks (Ikegamia and Makino 2009). A number of vaccines have been developed and assayed in veterinary species but there are no vaccine approved for veterinray used in European Union (Harrington, Lupton et al. 1980; Botros, Omar et al. 2006).

The vaccination should be given prior to an outbreak. Once the outbreak has occurred animals vaccination should not be implemented because there is a high risk of intensifing the outbreak (Davies 2010).

6.2.2 Prevention measures

The best and safest way for prevention of RVF and emerging and infectious diseases are good surveillance (Chevalier, Martin et al. 2008; Vrbova, Stephen et al. 2010) which can be divided into:

- Passive surveillance: follow-up of monthly disease reports from district veterinary officers and reporting by private animal health professionals;
- Active surveillance to detect new cases plays essential role in providing early warning for the veterinary and human public health authorities, *e.g.* by using sentinel herds at high risk areas for detecting the activity of the virus (Davies and Martin 2003), but this poses problem of high cost. Entomological surveillance can also be performed;
- Early warning: regulary watching the international RVF early warning system and follow up warning alerts of heavy rains, flooding, mosquito blooms and RVF events from the field (Anyamba, Chretien et al. 2009; De La Rocque and Formenty 2009);
- Vaccine: develop clear policy on vaccination with differents types of vaccine presented in above paragraphe (6.2.1).

In different parts of Africa sentinel herds has been used for early detection of RVFV to moniter the viral circulation in susceptible population as well as monitoring of climate parameters, *e.g* rainfall, flood, humidity, ground temperature, remote sensing satellite data (RSSD) like Normalized Difference Vegetation Index (NDVI), Sea Surface Temperature (SST), and Cold cloud Duration (CCD) (Davies and Martin 2003). Some recent retrospective studies used the combination of SST data of the Indian and specific occasions with NDVI. They approached 100% accuracy in the predicting period of RVF in east Africa (Anyamba, Chretien et al. 2009).

In river/wadi system like the Arabic peninsula the access to measurement of the basin excess rainfall monitoring system (BERMS) could help predicting virus activity a few months before the occurrence of RVF outbreak and giving time for taking prevention measures, such as vaccination of livestock and mosquito larval control methods. Moreover, these data are at low cost (Davies and Martin 2003; Chevalier, Martin et al. 2008).

6.2.3 Rapid intervention

Public health education and risk reducation plays a vital role in prevention of RVF cases messages to the community especially within affected areas should focus on:

- Avoiding high risk areas using glaves and clothing for the slaughtering pratices and handling sick animals;
- Avoiding consummation of fresh blood, meat and milk; food should be well cooked;
- Discuraging livestock slaughtering or stopping it during the outbreak;
- Protection of community and personal against the bites of mosquitos through insect repellents (containing 30-50 % DEET) using bed nets and wearing of light coloured clothes.

During the outbreak, the National Institute for communicable diseases in South Africa suggested that the most effective way of control for RVF relies primarily on the mass vaccination of the susceptible livestock population in the risk area and secondly on vector control and protection against their bites The effective vector control should target for larviciding control at mosquito breeding sites during the period of flood (NICD South Africa 2010).

6.2.4 Control

In order to control and prevent the disease, the following points should be taken into account:

- Monitoring the weather pattern using late predictive models;
- Monitoring the presence or absence of RVFV activity by sentinel herds;
- Targeting surveillance in risk zones in order to search for IgM positive animals;
- Establishment of regional network to follow up the virus activity, exchange information and organize the animals trade;
- Definition of the potential extensions zones of RVF on the basis of ecological and animal populations;
- Vector control: larvicidal treatment of mosquito habitats. Hormonal inhibitors, methoprene and larvicidal toxins give very good results but are difficult to use in some places where there is wide flood distribution;

- Movement control: all the exportation of livestock trade should be banned during RVF epizootic periods as well as the movement of animals from infected zones to free zones during the outbreak period;
- During the epizootic the close contact with animals should be avoided, particularly with their body fluid either directly or via aerosols. Indeed, it has been identified as the most direct transmitery factor for RVF virus infection;
- Laboratory workers and veterinarians have to be careful when they go in the field to collect samples from infected animals (gloves, masks, long-sleeved shirts and trousers).

Preparation for new outbreak

Following types of intervention and the actions should be implanting (ILRI /FAO 2009):

- Capacity building:

- Risk assessment: develop and maintain national veterinary services capacities to apply RVF contingency planning and response;

- Laboratory diagnosis: training of personal and upgrading of diagnostic laboratories to be able to rapidly diagnose RVF for livestock using OIE recognized standards (OIE 2000).

- Communication:

- Identification of target audiences;

- Participatory messages must be developed by the identification of the best methods of reaching different populations at risk

- Engagement of the local media especially science journalists to make them aware of RVF by bringing to their attention any relevant development.

- Surveillance

- Participatory disease surveillance (PDS) (Nzietchueng, Bernard et al. 2007);

- Mosquito surveillance: routinally surveillance of mosquito populations in risk areas combining traping with community reports and maps where RVF vectors are present;

- Evaluation of the impact and risk assessment as well using abreast of advance in RVF

- Passive surveillance

- Development of clear vaccination policy

- Using prevention and control technologies and approches and feed in RVF contingency planning. The result should be available to livestocks producers and traders (ILRI /FAO 2009).

For the earlier outbreak detection, more effective prevention and control interventions and more resources will be needed for animal disease surveillance. Currently most of resources for surveillance are allocated to human health so the collaboration between animal, human health agencies, organizations and experts must be improved (Breiman, Njenga et al. 2008)

7 Ecology and epidemiology of RVF

7.1 Transmission routes

7.1.1 Vectorial transmission

It is probably the main transmission route of RVF from animal to animal during inter-epizootic period (Figure 8). The ecology of *Aedes* and *Culex* is very different and therefore these species have different contribution in the epidemiology of the disease. *Aedes* females lay eggs on pond mud. When desiccated, eggs may survive several years in dry mud, hatching ‘en masse’ only once the pond is flooded (O'Malley 1990). Areas characterized by a succession of dry and rainy seasons provide a favourable environment for the development of a large *Aedes* population, and consequently for the virus transmission.

In contrast *Culex* females lay their eggs on the surface of pond water and the eggs do not survive desiccation but need a permanent water source to develop (Beaty and Marquardt 1996). Thus they are very abundant in irrigated areas, and will have major role in disease amplification when the virus is circulating in animal populations (Chevalier, Martin et al. 2008)

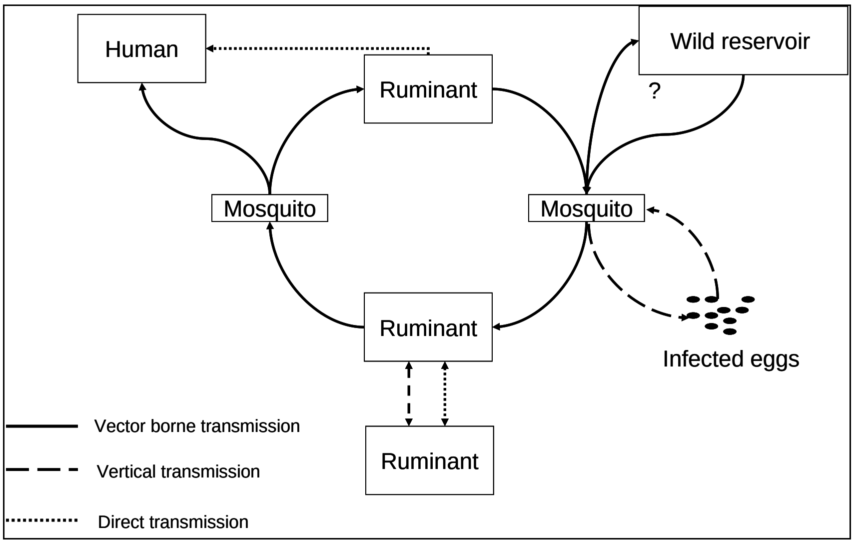


Figure 8: Theorical epidemiological cycle of RVF (Chevalier, Martin et al. 2008)

7.1.2 Direct transmission

During an outbreak of RVF the direct transmission is probably the main route of the infection for humans and probably for animals (Davis and Martin 2006) (Figure 8). Humans can be infected through the contact with infected tissues as with aborted products, or any other infected biological during the viraemia stage: the veterinarians and workers in the livestock industry are at risk including if they drink raw milk of infected animals (Shimshony and Barzilai 1983; Gerdes 2004). Meat can be source of infection but the virus is destroyed rapidely when the pH of meat decreases during maturation (Figure 9) (Marrama, Spiegel et al. 2005). Aerosol infection was confirmed in 1977-98 during the epidemic in Egypt, humans involved in slaughters of infected animals being exposed (Hoogstraal, Meegan et al. 1979; Brown, Dominik et al. 1981; Swanepoel and Coetzer 1994). Recently in 2008, in South Africa veterinary students and laboratory workers were infected after performing necropsies on infected animals (Bouloy and Flick 2009).There is no evidence of direct person to person infection (Shimshony and Barzilai 1983).

Figure 9 : Human contact with slaugthered animals in 2000 Tihama, Yemen.

7.1.3 Transovarial transmission

During inter-epidemic periods, RVF maintenance could be done by vertical transmission in floodwater *Aedes spp*, as described in (Figure 8) (Linthicum, Davis et al. 1985).

In addition, it has been suggested that between the periods of epizootic, RVFV could be maintained at low level of enzootic activity between the mosquito vector population and wild mammals such as rodents or wild ruminants, replicating the virus to titers that are sufficient for transmission while disease is at subclinical level (Pretorius, Oelofsen et al. 1997; Youssef and Donia 2002).

7.2 Ecology and epidemiological patterns of RVF

Most of RVF viral activity is cryptic at a low level, and not associated with any disease syndromes in human or animals. Some cryptic low-level RVFV activity may be occurring each year in many of sub-Saharan countries. Many african countries have found 15% to 35% of sheep, goats and cattle sero-positive for RVFV through most of the agro-climatic zones in their country, yet no clinical disease has ever been reported in human or in animals (Davis and Martin 2006).

Ecological factors and climate are considered to play a very important role in the epidemiology of RVF. Depending on the considered world areas, several studies have shown that the pattern of the disease was closely associated with climatic and/or ecological factors such as the agricultural context, the rainfall levels and patterns, floods, sea surface temperature (SST) and the normalized difference vegetation index (NDVI).

Most of the epidemics and epizootics observed occurred after unusually heavy rainfall events or in association with the construction of dams, like the RVF outbreaks in 1977 in Egypt and in Senegal in 1987 (Flick and Bouloy 2005). Many hypotheses were associated to this northern extension from Sudan to Egypt either by passive dispersal (thought the wind) of infected mosquitoes or infected humans on commercial airlines or movement of infected animals, especially camels, along the trade routes with Sudan (Hoogstraal, Meegan et al. 1979; Sall, Macondo et al. 2002). On the other hand after the construction of the Aswan dam on Nile River, ecological modifications induced vectors and animals host population changes in the area. These modifications could have facilitated the RVF emergence in Egypt in 1977 (Shope, Peters et al. 1982). Indeed, the subsequent irrigation of vast areas used for cultivation following the dam building in 1971 provided local mosquitoes with ideal breeding habitats and resulted in high numbers of *Culex* during the following summer. In addition, increases in grassy areas attracted breeders from foreign areas leading to a very high density of ruminants in the region. A similar sequence of events was associated to the building of the Diama dam in the western African countries of Senegal and Mauritania, although, in this case, the virus was believed to have been present prior to the construction of the dam (Saluzzo, Digoutte et al. 1987; Fontenille, Traore-Lamizana et al. 1994; Zeller, Fontenille et al. 1997; Fontenille, Traore-Lamizana et al. 1998; Chevalier, Delarocque et al. 2004; Chevalier, Mondet et al. 2004).

Different patterns of RVF can thus be observed in the different eco-climatic regions:

- In East Africa, the occurrence of RVF outbreaks has been clearly correlated with unusually heavy rainfall as associated with El Niño phenomena (Davies and Highton 1980; Davies, Linthicum et al. 1985; Linthicum, Anyamba et al. 1999). In December 1997 the outbreak occurred after a rainfall of 60 to 100 times above its average level (CDC 1998). The outbreak that occurred in 2006 in East of Africa also followed above normal rainfall levels (FAO ; EMPRES 2007). After three months, severe outbreaks of RVF hit the Horn of Africa (CDC 2007), more particularly Kenya, Tanzania and Somalia. In Kenya from the 30th November till march 2007, 684 human cases including 155 deaths were recorded; in Somalia 114 human cases were detected with 51 deaths; in Tanzania 264 cases were recorded with 109 deaths (CDC 2007) as well as thousands of animals cases (ProMed 2006; WAHID OIE 2007). Using the rainfall and NDVI data coupled with satellite observation it may be possible to predict the outbreak up to 5 months before.

- In semi-arid zones (Saudi Arabia, West Africa) the climatic factors have not been implicated in outbreaks of RVF. Other factors such as herd immunity could explain the cyclicity of the disease emergence, with virus circulation recorded every five to six years during the last 20 years. This cyclicity has been observed in northern Senegal and southern Mauritania in 1987 (Jouan, Adam et al. 1990), Mauritania in 1998 (Nabeth, Kane et al. 2001), Mauritania and Senegal in 1993 (Zeller, Fontenille et al. 1997) and recently in 2002-2003, which resulted in severe animals losses in Mauritina, Senegal, Gambia and Mali (Thiongane and Martin 2003). A similar periodicity has also been observed in Egypt. The inter-epizootic period matches with the time when the herd are renewed in irrigated zones in Egypt (Martin, Chevalier et al. 2008).

- In high rainfall forest zones of the coastal and central Africa, as well as highlands areas of Madagascar, the RVF cycle is poorly understood. Wild animals could act as reservoir, and the virus could be maintained between mosquitoes and these animals. The determinants of outbreaks remain unknown.

7.3 The effects of climate on the transmission cycle of RVF

The three fundamental components of the epidemiology of RVF, the vector, the host and the virus, are affected by climate. In particular, the hatching dynamic of *Aedes* mosquitoes, the main reservoir/vector of RVF in East Africa, is highly dependent on the rainfall pattern since the eggs need to be flooded to hatch (Meegan, Baily et al. 1989; Mondet, Diaïté et al. 2005)

In East Africa, remote sensing data can be used to estimate unusual rainfall and consequent vegetation growth (via the NDVI). This data is used to predict RVF activity before epidemics occur (Linthicum, Anyamba et al. 1999; Anyamba, Chretien et al. 2009). The correlation with heavy rainfall and RVF outbreaks displays different patterns in West Africa (Chevalier, Delarocque et al. 2004), where it remains poorly understood.

7.4 Dissemination

History of the disease suggests that trade and transport may affect the geographical distribution of RVF and contribute to a large scale sometimes continental - spread of the disease, and to the introduction of the virus into disease-free areas via livestock movements. Infected camels may have introduced RVFV into Egypt from Sudan during the 1970s (Abd El-Rahim, El-Hakim et al. 1999). Similarly, as demonstrated by the genetic similarity of Kenyan and Saudi Arabian strains, the virus probably was introduced into Saudi Arabia from Kenya by ruminants (Shoemaker, Boulianne et al. 2002).
There is also a huge ruminant trade between sub-Saharan Africa and northern Africa. During the next few years, the muslim feasts of Eid-ul-Fitr and Eid al-Adha will occur between September and November, i.e. when the RVF risk is high (end of the rainy season in Sahelian Africa (Chevalier, Lancelot et al. 2005), the virus could be introduced into the area, then threaten Europe where potential RVF vectors have been identified (Chevalier, Pépin et al. 2010) .

Increased temperature may affect the biology of the vectors by increasing feeding frequency and eggs production and decreasing the length of the development cycle and the extrinsic incubation period (Paul Reiter 2001). Indeed, this may result in a high vector density and increased vector's capacity to transmit the virus and thus lead to a high transmission rate. Climatologists expect that global climate change will induce an increase of temperature of 1°C to 3.5°C during the 21st century (Global Warming and climate 2010). This may result into significant shifts in the geographical range and seasonal activities of many vectors species (McMichael, Haines et al. 1996). Climate change could have a major impact on the occurrence and distribution of the disease because of more frequent extreme weather events and also because of its impact on the biology of the arthropod vectors on their geographical distribution.

The presence of potential vectors such as *Cx. pipiens* in Northern Africa (Maghreb) and in Southern Europe indicated that the settlement of RVFV could be effective in case of the introduction of the virus into countries of the Mediterranean basin (Moutailler, Krida et al. 2008). In addition, the increase of ruminant trade between the neighbouring countries Tunisa, Algeria , Lybia , Mauritania and Mali increase the risk of expansion of RVF to Northern Africa (Fakhfakha, Ghrama et al. 2010). Another study showed that *Ae. tritaeniorhynchus, Ae. vexans,* and *Cx. erraticus,* neartic mosquito species widespread in North America, were efficient vectors for transmission of RVF (Turell, Dohm et al. 2008.). This risk of RVF spread is real and could rapidly occur in many Western countries including the United States (Turell, Dohm et al. 2008.). A single infected viremic animal that enters the naïve country could be sufficient for the initiation of an outbreak (Bouloy and Flick 2009).

Chapter 2: Geographical context

1 General presentation of Yemen

The Republic of Yemen is situated at the south western corner of the Arabian Peninsula, between 12° and 17.7° north and 43.5° to 52° east (Figure10). It includes many islands, the largest one being Socotra in the Arabian Sea and Kamaran situated in the Red Sea. The country is bordered by Saudi Arabia to the north, Oman to the east, the Arabian Sea to the south and the Red Sea to the west (Figure 10).

The land area of Yemen is about 55,000 km^2. According to the World Fact book (July 2006), the population is estimated as 22,858,238 inhabitants with a growth rate of 3.46% per year. The capital is Sana'a (Alabsi 2006).

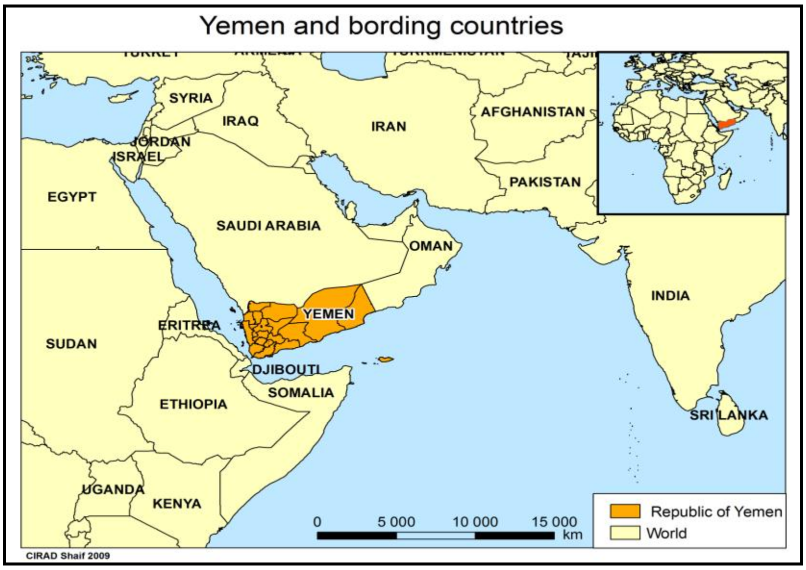


Figure 10: Location of Yemen

2 Topography and soils

Yemen has various landscapes from sea level to inter-mountain plains, steep slopes and rugged high mountains. The topography is dominated by mountain ranges running parallel to the Red Sea coast, with three ridges interspersed by upland plains. These mountains ranges rise from sea level to over 3,600 m within 100 km from the Red Sea. In the Southern part of the country the ranges merge with ranges running parallel to the coast of the Gulf of Aden reaching an altitude of about 2,000 m.

According to altitude and geomorphology, the country presents:

- Low Altitude Mountains (Western mountains-Tihama foot hills, Southern-and Southeastern mountains), medium altitude mountains (Western mountains, Southern and Southeastern mountains) and high altitude mountains. The approximate altitudes of these lands are 1000, 1800 and above 1800 m respectively;

- Highlander plains;
- Deserts;
- Coastal plains characterized by the *wadis* where spate irrigation is implemented, the biggest one being the Wadi Mawr, the largest drainage system in Yemen (Tahir and Noman 2004). Spate irrigation is a typical water management system in semi-arid environments, where flood water from mountain catchments is diverted from river beds and spread over large areas every rainy season (Chevalier, Martin et al. 2008).

The principal soil types in the various physiographic regions are as follows:

The soils of the Coastal Plains are either alluvial fans or coarse inter-*wadi* soils. In *wadis* and flood plains the soils are loamy to silt and clay which is considered as arable land favorable to agriculture. The inter-*wadi* areas are dominated by dune formations and coarse skeletal sandy soils subject to wind erosion. The coastal fringes of the plains consist of very saline tidal flats or known as "sebkhas".

The soils of the Western Slopes range from bare rock and very shallow soils near the mountain peaks, while stony and very stony calcareous soils with pH around 8 and low organic matter occur in the middle slopes (Tihama Development Authority 1986). The lower slopes have generally deep silty and loamy soils. This region has relatively extensive alluvial loams and silt loams which make good agricultural land.
Around Ibb (Southern Highland), thick loess deposits occur which have developed deep silty soils. The south of the Midlands is occupied by rock outcrops with pockets of shallow soils. The Highlands have large stretches of plains between the mountains which constitute extensive loamy, silty and fine silty soils on level surfaces, one third of which bear organic matter within the surface layer. Associated with these soils is a minor component of clay soils, which also have a dark layer rich in humus. These constitute very productive agricultural lands. On the lower slopes of the highlands silt loams and silty clay loams prevail, while the flat basins comprise silty and loamy soils.

The Eastern Slopes region comprises mainly rock outcrops, with some shallow soils confined to pockets. Deep loamy soils are only encountered within local depressions and *wadis*. In the Eastern Plains, *wadi* flood plains have deep alluvial soils which are medium textured, while the restricted areas where flooding takes place regularly, have stratified sandy loams and silt loams (FAO 1997).

3 Climate

Yemen has a semi-arid to arid climate. Its topography and its geographical situation between 12° to 17° north are favorable to tropical and sub tropical sea influence and Saharan climate impact.

Two rainy seasons occur each year, the first in spring (March to May) and the second in summer (July to September). Three large bodies of water affect the climate: the Indian Ocean (including the Gulf of Aden and the Arabian Sea), the Red Sea and the Mediterranean Sea. They are the sources of moisture for the passing air masses. The rainfall depends on two main mechanisms: the Red Sea Convergence Zone (RSCZ) and the monsoon inter tropical Convergence Zone (ITCZ). The first one is active from March to May. Its influence is most noticeable at higher altitudes in the western part of the country. The second reaches Yemen in July - September, moving north and then south again so that its influence lasts longer in the south (Farquharson, Plinston et al. 1996). Finally, rainstorms in the winter months of December and January are attributed to the influence of the Mediterranean Sea.

The climate is also strongly influenced by the mountainous nature of the country. Seaward exposed escarpments such as the Western and the Southern slopes receive more rain than those facing the interior. Local topographic features cause similar lee side effects. Average temperatures decrease more or less linearly with altitude. The rise of the air masses over the mountains provides a cooling mechanism, which stimulates the rainfall. The variability in rainfall over both time and space is considerable. Rainfall is predominantly in the form of localized storms. This results in great differences in amounts of rainfall over relatively short distances. A year may be relatively wet in one area, but dry elsewhere, even if distances are modest. There is a clear relationship between mean annual rainfall and topography. Rainfall rises from less than 50 mm along the Red Sea and Gulf of Aden coasts to a maximum of 500-800 mm in the Western Highlands and decreases steadily to below 50 mm inland.

Average temperatures are also dominantly controlled by altitude. There is an approximate linear relationship, with an average temperature gradient of about 0.65° C per 100 m difference in elevation. At lower altitudes (below 500 m) in coastal areas, this relationship is disturbed by the moderating effect of the sea.

The difference between the average temperature of the warmest and the coolest months of the year is not constant over the zones. In coastal areas and the Western and the Southern slopes it is generally less than 10°C, but in the arid interior it increases to about 15°C. The average daily range is modest near the coast (less than 10°C), but may exceed 20°C at higher elevations and in the arid interior. Above 2 300 m frost occurs regularly between mid October and March.

Coastal relative humidity shows a strong 80%, while lower annual average value (50 to 70%) is observed in the inland. In the mountain areas values vary between 30 and 60%, except in the high rainfall areas where values are between 50 and 70%. In the arid interior values are below 40%. The variation of relative humidity over the year follows the rainy seasons; however, in the arid zones the humidity is relatively higher in the cool season (AREA 1997).

The Tihama rainfall stations record regularly the rainfall amount (Figure 11).

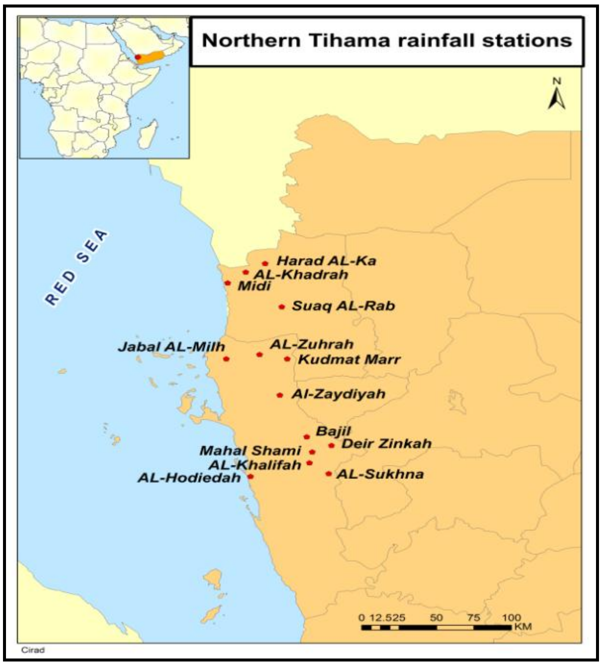


Figure 11: Rainfall stations in Northern Tihama, Yemen

4 Agriculture and livestock production in Yemen

Agriculture is a major sector of the national economy of Yemen. Agricultural activities are the prime occupation of about half of the population. Of the work force of 3,100,000 people, 58 % are involved in agriculture (10.9% are involved in trading and vehicle maintenance and 9.9% are the government sector social security, employees and army) (CSO 1999). Agriculture contributes to 21% of the Gross Domestic Product (GDP), but this proportion is declining.

Yemen has five main agro-ecological zones, the Coastal Plain, Western Mountains, Highland Plain, Eastern Mountains and Eastern Desert Plain (Alabsi 2006).

4.1 Ruminant livestock production systems

Livestock are estimated to contribute to about 20% of the agricultural GDP. In addition, nearly 80% of farms are either pure livestock producing, or mixed (mixed farmers 59%, livestock farmers 20% and arable farmers 21%). Women are prominent players in animal production which provides them with essential food, financial security and independence (Alabsi 2006).

Livestock distribution is variable according to regions, feed resources and agricultural activities:

- Eastern Zone: 33.75% of the total livestock population and 3.7% of the cattle population.
- Coastal lowland: 15.4% of the total livestock population and 25.1% of the cattle population.
- Central highland: 10% of the total livestock population and 12.4% of the cattle population.
- Northern highland: 24% of the total livestock population and 24.4% of the cattle population.
- Southern upland: 17% of the total livestock population and 33.4 of the cattle population

There are 1,422,409.4 Tropical Animal Units (TAU) in the highland, 604 382.5 TAU in the coastal plains and 1 009 040.5 TAU in the desert region (Alabsi 2006). Thus, livestock production systems vary from traditional pastoral to agro-pastoral systems and recently small-scale intensive animal production units. Pasture-fed livestock has been traditionally practiced and is a prominent feature of rural economy and agricultural activities in many parts of Yemen.

The type and number of livestock bread in Yemen between 2000 and 2006 are presented in (Table 5).

Item	2000	2001	2002	2003	2004	2005	2006
Sheep	6,193	6,483	6,548	7,819	7,899	7,980	8,042
Goats	6,918	7,246	7,318	7,707	7,785	7,864	8,197
Cattle	1,283	1,342	1,355	1,418	1,433	1,447	1,463
Camels	2,53	2,64	2,67	3,50	3,53	3,570	3,471

Table 5: Livestock numbers in Yemen (, 000) 2000-2006 (Source FAOSTAT)

4.2 Animal Quarantines

Due to the particular geographical position of Yemen, it is considered a crossing point for animal trading between the Horn of Africa and the Arabic Peninsula. Traditionally, livestock traders prefer this route for the proximity of exportation ports of the African continent (mainly in Djibouti and Somalia) with the Yemeni ports. Human health and veterinary legislation in Yemen stipulate that all imported livestock must be held for quarantine inspection on arrival. However, forcing this regulation has some difficulties due to inadequate facilities in the entry point. Currently the Ministry of Agriculture & Irrigation identifies several quarantines and check points for export and import of live animals and animal products: Mukka Quarantine on the Red Sea is considered the main entry point of all livestock species; Mukalla quarantine on the Arabian Sea is considered the second largest quarantine for entry of livestock (small ruminants); there are also two check points at the north-west border with Saudi Arabia (Harad check point) for animals, animal products and for one– day old chicks, another check point is in the east boarder of Yemen with Oman (Haof check point); Sana'a Airport receives animal inputs (Vaccines, drugs etc) and animal products as well as hatching eggs and one-day old chicks; finally Hodeidah and Aden Ports for animal inputs and animal products. All quarantines and checkpoints do not include a sufficient number of qualified staff and of other needed facilities. Therefore efforts are needed to improve quarantine facilities to insure good and smooth operation at all the five entry points.

With the support from the Agriculture Arab Development Organization, a study was conducted to develop the quarantine stations for both Plant and Livestock. Designs were done for refurbishing Al-Mukha quarantine, but it needs some revision to fulfil the standard requirements for facilities like this (Figure 12). The cases of the two other main quarantines Al Mukalla and Aden (Figure 13) was also considered.

Traditional nomadic routes cross international boundaries and smuggling livestock along the borders is common. It is very likely that disease is imported from countries such as Somalia despite stock arrives with health certificates.

Figure 12: Al-Mukha quarantine during high peak period Ramadan

Figure 13: The three main animal quarantines in Yemen

5 The regions affected by RVF in 2000-2001

5.1 Tihama Coast

The coastal region of Tihama is situated in the western part of Yemen. It is bordered by the Kingdom of Saudi Arabia in the North, the Red Sea in the West, the bay of Bab Al Mandab in the South, the mountains of Tihama in the East. It has roughly a length of 450 km from North to South and a width of 30 to 60 km, with a surface area of 22000 km² (figure 14). It includes four Governorates: Hodiadah (22 districts), Hajjah (11 districts), Saddah (2 districts) and Taiz (5 districts).

In this semi-arid region, the climate is dry and hot with temperatures ranging from 30-35°C in summer and 25-28°C in winter. The percentage of evaporation is high (2400-3000 mm) and the relative humidity ranges from 55 to 70%. The mean annual rainfall varies from 50 to 350 mm/year for the whole Tihama region.

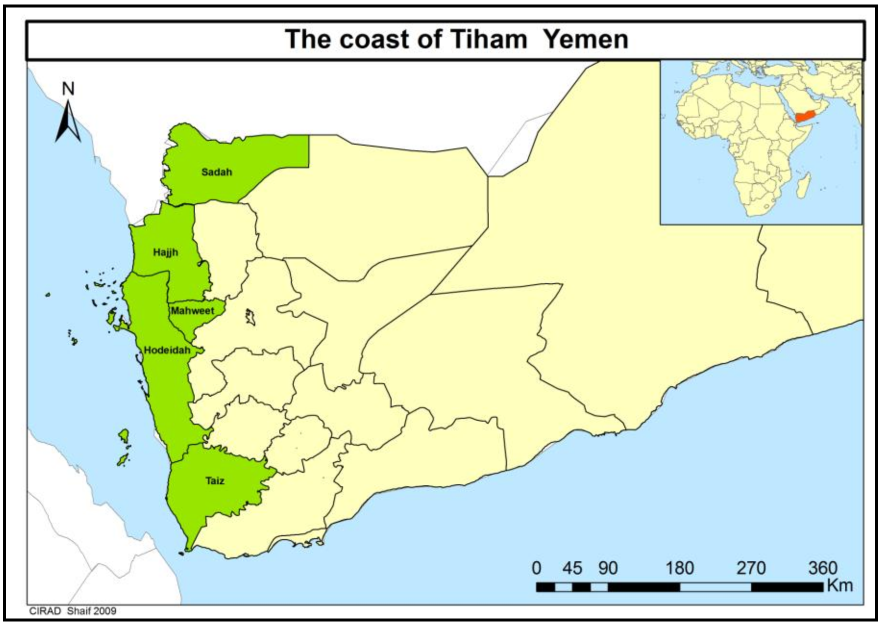


Figure 14: The coast of Tihama (in green).

Many *wadis* are crossing the coast from the mountains to sea (Figure 15). The main *wadis* and their characteristics are listed in Table 6.

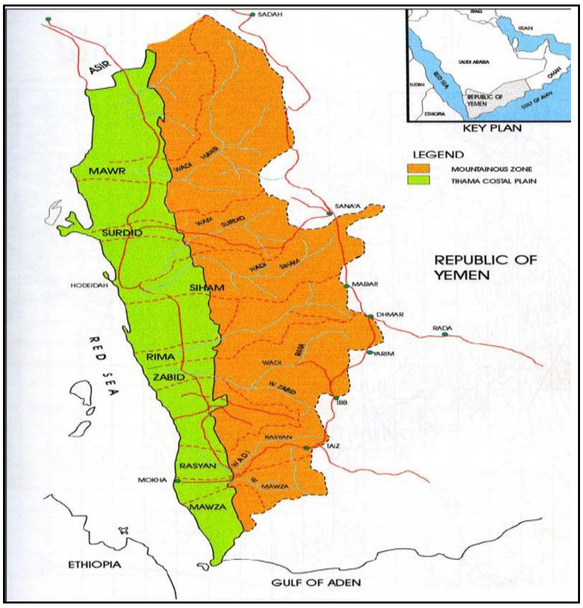


Figure 15: Map of the main *wadis* in the Tihama Coast showing the catchments areas (Source: Tihama development authority, Hodeidhah, Yemen)

No	Name of *wadi*	Governorate	Catchment area	Capacity of the lower catchment areas	Length of *wadi* (km)	Annual % of rainfall (mm)
1	Wadi Mawr	Hodidah	8180	820	310	430
2	Wadi Surdod	Hodidah	2750	440	107	550
3	Wadi Siham	Hodidah	4900	690	187	430
4	Wadi Rama'a	Hodeidah	2760	490	123	580
5	Wadi Zabeed	Hodidah	4560	770	152	530
6	Wadi Alkyedah	Hodidah	580	750	13	610
7	Wadi Maryar	Hodidah	290	630	14	390
8	Wadi Naklah	Hodidah	510	240	34	580
9	Wadi Tihama	Hodidah	430	260	21	410
10	Wadi Arfan	Hodidah	240	730	6	22
11	Wadi Harad	Hajjah	910	420	27	500
12	Wadi Hayran	Hajjah	430	320	22	560
13	Wadi Buhal	Hajjah	250	400	16	740
14	Wadi Rasyan	Taiz	1990	220	75	500
15	Wadi Mouza'a	Taiz	1480	560	65	500
16	Wadi Samdah	Taiz	160	1530	6	240

Table 6: Characteristics of the main *wadis* in Tihama coast, Yemen. Source: Tihama development authority, Hodeidah, Yemen.

5.2 Wadi Mawr

Located on the Tihama Coast, it is the largest *wadi* in Yemen with upper catchment areas of 8180 km^2 and lower of 820 km^2 (Figure16). Its length is 310 km, with an average annual rainfall around 430 mm. Since the establishment of an irrigation scheme in 1986, the agricultural activities increased significantly, including cultivation of different fruits mainly mangos, but also with the growing of grains, livestock breeding and fattening of small ruminants for re-exporting to Saudi Arabia. The development of these activities resulted from the changes of water management schemes and human's habitats in the *wadi*.

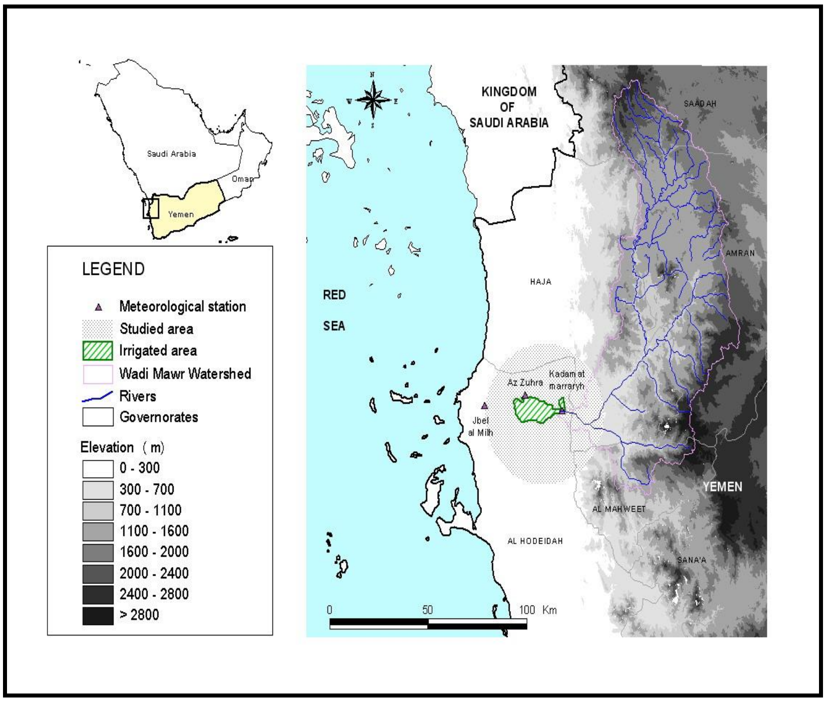


Figure 16: The catchment area of Wadi Mawr with irrigation scheme and elevation

Chapter 3: A review of socio-economic impact of RVF worldwide in relation to the case of Yemen

(Article accepted in the journal "Epidemiology and Infection")

A review of the socio-economic impact of the Rift Valley fever with a special focus on the Horn of Africa and the Arabic Peninsula

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Running head: Rift Valley Fever economic impact

SUMMARY

Rift Valley fever (RVF) virus has been reported in humans and animals in approximately 30 countries worldwide; most of them being located in Africa. The most direct economic impact of RVF on pastoralist community is the loss of income and potential food insecurity. RVF is also a public health issue as it may cause severe disease in humans. The risk of introduction of RVF in disease-free countries via importation of an animal from an infected country is real and could restrict access to export markets with dramatic economical consequences. However, few studies have been conducted on the socio-economic impact of RVF. This paper reviews the socio-economic impact of RVF in countries of the Horn of Africa and the Arabic Peninsula. The main objective of this review is to emphasize the heavy economic burden linked to this zoonotic disease. Socio-economic studies are critical for decision-makers in their choices related to RVF disease management.

Keywords:

Rift Valley fever, Economic Impact, Horn of Africa, Yemen.

INTRODUCTION

In pastoral societies, livestock production contributes directly and indirectly to food security and nutrition (self consumption of animal products) and to production of valuable goods and services (e.g. transport; manure for fertilising; income from marketing and trade of products). In the Horn of Africa, pastoralists play an important role in the economy of the countries. They represent 60% of the community and in Somalia alone, 90% of the total resources of the country are coming from the exportation of livestock to the Middle East [1].

Animal diseases may have a major impact on food availability and quality for the poorest communities. Rift Valley fever (RVF) is a zoonotic disease of domestic ruminants and humans, caused by an arbovirus belonging to the *Phlebovirus* genus (Bunyaviridae family). RVF virus has been reported in human and animals in approximately 30 countries up till now, most of them being located in sub-Saharan Africa [2]. The virus is transmitted between ruminants by mosquitoes, mainly from *Aedes* and *Culex* genera, and causes abortion and high mortality among offspring of domestic ruminants during epizootics [2;3]. Human infection by the RVF virus may result either from bites of mosquitoes, or exposure to body fluids during caretaking, and with their carcases and organs, during autopsy, slaughtering, and butchering [4].

Since the first declared outbreak in Kenya in 1930 [5], RVF has been expanding its range, infecting most of sub-Saharan African countries, as well as Madagascar. Most of RVF viral activity is cryptic and not necessarily associated with any disease syndromes in human and animals. Some cryptic low-level RVF virus activity may be occurring each year in sub-Saharan countries without any reporting [6;7]. Some African countries (e.g. Burkina Faso, Botswana, Angola, Central Africa, Niger, Chad, Cameroon) have detected antibodies (Immunuglobulin G or M) against RVF virus in ruminants (up to 35% prevalence in sheep, goats or cattle) but yet no clinical disease has ever been reported neither in human nor in animals [8].

In September 2000 Yemen and Saudi Arabia were simultaneously affected for the first time [9;10]. This was the first record of RVF outbreak outside the African continent (Ahmad K 2000; Alqadasi.M 2009) The geographical distribution and recent spread of RVF proves the virus' ability to expand and adapt to new areas, and threaten more human and animal health (Figure 1) [2]. Even if poorly documented, it is known that the direct and indirect economical impact of RVF may be huge. However, few studies have been conducted to estimate the level of this impact.

The most important direct economic impact of an animal disease such as RVF is loss of production and/or productivity resulting in the lost of income for the livestock producer. Due to massive abortions and high mortality among offspring of domestic ruminants RVF induces losses in production and livelihood that may be dramatic for the poorest. Rift Valley Fever not only has a direct impact on local livestock production but could induce spill over effects on the entire livestock industry with the domestic marketing and movement restriction or with absolute international trade bans put on livestock and livestock product [13-15]. Infected countries have implemented heavy cost control measures such as mass vaccination and vector eradication to try to contain the disease [16;17]. Therefore the “endemic” status of the disease in countries with recurrent outbreaks will potentially result in potential long term financial investment for disease control and surveillance. RVF is also a public health issue : most infections in human are associated with moderate to severe nonfatal influenza-like illness; however few patients may develop ocular lesion, encephalitis, or severe hepatic disease with hemorrhagic manifestation which could be fatal [18-20]. The heavy economic burden associated with the loss of many human lives has to be taken into consideration in any economic impact assessment.

This paper reviews the socio-economic impact of RVF as demonstrated by various authors and for various economic levels (micro, meso, macro) and temporal scales in already afflicted countries of the Horn of Africa and the Arabic Peninsula. The main objective of this review is to emphasize with various perspectives the heavy economic burden linked to this zoonotic disease and provide relevant information to decision-makers on the importance of RVF disease management.

Direct impact of RVF on livelihoods of producers (microeconomic level, household economy)

Livestock contributes to the livelihood of more than two thirds of the world's resource-poor people insuring food and nutritional security and has a wide range of socio-cultural roles [21]. Livestock products are an important source of human daily intake of proteins and also serve as safety net of households in times of lower levels of food production and/or other occurring calamities, such as illnesses [22]. Indeed livestock often serve two crucial functions: as an instrument to gradually build household' assets (generally starting with small ruminants and reaching cattle) and as a source of regular cash and emergency funds during the year cycle [23;24]. The most direct economic impact of RVF is derived from losses of production and/or productivity resulting in less income for the livestock producers and potential food insecurity. If the farm economy is diversified enough i.e. if there are other activities/opportunities to generate income, the impacts can be mitigated. However, if the household economy depends only on one type of farming system and one type product, the households are extremely vulnerable, impacts can be serious, and local food security can be threatened. The economic impact also depends on the response strategies adopted by farmers like possible market shifts and adjustments and on their capacity to implement them. The loss of the farmer's "well-being" will generally be lower than the value of the lost product, except where the farmer is wholly dependent on the affected production, which is quite often the case in developing countries particularly in the pastoral areas of the Horn of Africa. Direct losses are therefore and primarily the result of the disease itself and may be very high when mortality rates are evaluated between 50 percent (%) and 100% of young's which is the case for RVF (Table 1).

Pastoralism provides a critical mean of survival in the Horn of Africa, accounting for the livelihood of 15 to 20 million people in Djibouti, Eritrea, Ethiopia, Kenya, Somalia and Sudan [25]. RVF has an important economic impact on those livestock producers with firstly the immediate loss of stock due to the sudden high mortality rates occurring in young ruminants (sheep, cattle, goat and camel). Therefore, it will hamper normal marketing levels and patterns (volume and price). These effects are generally considered with a short term time horizon (yearly cycle). Secondly such a natural destocking is coupled with a diminished capacity of pastoralists to assure the renewal of animals for sustaining a balanced herd composition and a stable number (steady state). This aspect is linked with the high abortion ratio provoked by the disease which effects are perceived on the long run which is a second time horizon to be considered (Table 1) [5;26].

As an illustration, in the North-East province of Kenya (the poorest Kenyan region) where livestock is the major resource with an average per capita income of 21 USD mainly generated by livestock marketing, a 75% loss in the average annual household income was observed during the 2006-2007 RVF outbreak [16]. This was attributed to both morbidity and mortality of livestock (including losses of livestock from stamping-out policies implemented to attempt control of the disease). The forecast reduction in herd size due to the high abortion rate during this outbreak was estimated between 2 to22 time's reduction according to the animal species (2 for cattle; 8 for goat and 22 for sheep). This outbreak also led to a decline of 50% in the price of raw milk in Kenya and the effect of lower consumption of milk was still being felt by the producers a year on after the outbreak [27;28].The resulting value of total milk lost during the Kenyan outbreak was therefore estimated around 2 million USD resulting from both yield and price factors [29].

During the 2000 outbreak in Yemen important losses in livestock and an increase in the prices of white meat, fish and poultry resulted in less intake of animal protein to poor families. The total losses in livestock due to the 2000-2001 outbreak of RVF was equivalent to 0.6 million USD with high death rates and abortion in sheep (39%), goats (28%), cattle (18%) and camel (14%) [17].

Direct impact of RVF on livestock industry (domestic or transnational value chains, meso economic level)

The production of processed meat and other animal-based food products generates income, jobs, and foreign exchange for all stakeholders in the livestock industry. Consequently, an epizootic can affect the industry's stakeholders upstream (inputs, genetic resources) and downstream (slaughterhouses, butchering operations, processing, marketing) in terms of jobs, income or market access.

In Yemen, veterinarians and public health authorities were not prepared to deal with this disease as it was declared for the first time in the country [30]. When the disease was first introduced in Saudi Arabia and Yemen in 2000 the impact was high as the diagnosis and confirmation of the disease were delayed, despite the reaction of the governments and international organizations [11;31]. With a high rate of animal mortality, the incurred tangible losses for the cattle market in Saudi Arabia in 2001 was estimated to 5.3 million USD [32]. The impact on livestock marketing is more severe during major religious public holidays where market values of animals can increase considerably over a short period of time. In addition, meat markets were closed for three months in the affected and neighbouring governorates. The overall cost for the livestock industry (including butchers and middle men) was estimated to more than 15 million USD. (Table 3) [33].

In Kenya, following the RVF outbreak of 2007, the impact of the closure by the Government of the Garissa Market on the livestock industry in the nearby region had dramatic consequences. This market is an important livestock market for Somalia, the North-East region of Kenya and parts of Ethiopia: 75% of the cattle coming to the market originate from southern Somalia. This market is also a major transit and assembly trade point, supplying other major markets in Kenya especially Machakos, Nairobi, and Mombasa and other coastal towns (Figure 2). The three months closure of the market (from January till March 2007) resulted in more than 25% decrease in the price of mature cattle in Garissa. The total losses induced for the value chain by this closure were estimated around 10 million USD, making it significant not only for the pastoral economy within the region but also for urban consumer' populations, transporters, and local authorities. However, this impact was only transient as from October 2007 the meat prices doubled in Garissa Market to about USD 300 and have remained high since [34;35]. This highlights again the importance of considering an appropriate time horizon to capture all necessary effects of an outbreak. Moreover very bad climatic conditions at the time (heavy rains) made the main roads impractical in the affected region, and the price of essential goods increased by 100% (e.g. the price of the kilogram of sugar was doubled) [16]. This highlights the importance of considering all related factors including the environment before concluding on causal economical relationships observed during an outbreak.

A case study performed by Wanyoike and Rich in 2008 on the socio-economic impacts of the 2007 RVF outbreak on the North-eastern province livestock marketing chain in Kenya has shown that RVF had many adverse impacts on producers and other actors of the livestock production and marketing chain [16]. The impact on producers were food insecurity, lack of income and reduced levels of wealth as mentioned previously, whereas livestock traders, slaughter houses operators and butchers suffered from income losses due to a decrease or end of business; unsold stock; lowering in prices. In many cases those actors could not resume their activities even after containment of the outbreak. The impact of the outbreak was also felt by actors in other sectors due to the multiplying effect of livestock production (livestock and meat transporter; livestock brokers and marking boys; government collecting taxes). The net losses in business for these actors in Kenya were estimated around 30 millions USD [29].

Indirect impact related to trading ban (transnational value chains, meso economic level)

Loss of access to regional and international markets generally has more significant economic implications than just production losses. For some countries in the Horn of Africa taxation on livestock exports is the main source of government revenue [36;37]. The threat of the occurrence of an epidemic diseases such as RVF could restrict access to export markets when a ban is enforced therefore affecting the public treasure [23].

Even if it remains unclear if the virus has persisted in the Arabic Peninsula since the 2000 outbreak, the risk linked to RVF re-introduction during importation from the Horn of Africa to the Arabic Peninsula should not be underestimated when considering that RVF virus is still circulating as confirmed with the 2006-2007 outbreaks in Kenya. Exported animals are usually live males which if infected might escape prompt detection (as classical clinical sign of RVF is abortion) which could lead to introduction of the infection in the importing country [8]. The short transport distance between the Horn of Africa and the Middle East (2 days for a ship with a capacity of 500-2000 animal heads) makes it possible for the viraemic animals to spread the infection (2-3 days) if not quarantined at destination [7;38]. Besides, in this region, the animal health infrastructure and laboratories facilities could be limited and might not be able to detect the disease prior to transportation. Given the zoonotic nature of RVF, the loss of confidence by an importing country can trigger a lasting embargo and have major economic and social repercussions.

Middle East countries import millions of animals each year and more especially during the religious festival period which lasts for three months starting from the month of Ramadan until Eid Al-Kaber and during the pilgrimage festival of Hajj to Makah (the number of imported animal heads could triple during this time) [39].

Following the 1997-98 outbreak in East Africa [40;41], Saudi Arabia imposed a ban for sanitary reasons on the importation of livestock from the Horn of Africa which lasted for 18 months [13]. It was the first ban in the history of animals trade linked to RVF outbreak in the region. This ban led to very serious negative impact in the whole region and more especially in Somalia. Somalia livestock market completely collapsed with a decline of more than 75% in exports which represent 90% of its total income. The estimated losses were greater than 100 million USD [30].

In 2000, following the introduction of the virus and the first outbreak of RVF in the Arabic peninsula, six gulf states (Saudi Arabia, Qatar , Bahrain, Oman , United Arab Emirates and Yemen), quickly banned the importation of livestock from the Horn of Africa for another two years [30;42-44]. Following this ban, the red meat market in Yemen which accounts for 75% of the consumer demand and relied for 25% on the importation was heavily impacted. The cattle population imported from 2001-2002 decreased by more than 99% and was still 50% lower than before the trade ban in 2003 [33]. The national impact of the 2000 RVF outbreak was important with a total lost of 107 million USD which represented nearly 1% of the Gross Domestic Product (GDP) calculated using the Purchasing Power Parity value (PPP) (Tables 2 and 3). This includes a revenue loss from livestock trade ban greater than 80% of the total cost (15 millions USD losses for the government from custom taxes and 27 million USD profit losses for traders) [33]. The economic impact was even greater for the exporting countries from the Horn of Africa and Somalia in particular which accounts to 85% of its ruminant export to Yemen [33].

Prior to the first 1998 ban, the size of the export market from Somalia to Saudi Arabia and the Emirates varied from 1.3 to 3 million of animal heads per year with an estimated value of 600 million USD [13], Saudi Arabia representing 66% of the total. During the 2001 ban this number dropped by 75% to around 0.34 million [45]. The estimated losses for Somalia were greater than 320 million USD [37;46].

Somalia is an edifying example as its economy relies mainly on livestock production and trade and 60% of its population depends on meat and milk (Table 1) [1;13]. Somalia also holds the Berbera sea port which is the major and unique port for the exportation of live animals from the Horn of Africa to Arabic peninsula and more especially to Yemen (Aden) (Figure 2) [48]. Not only the ban in this region affected each house and resulted in disturbing and instability of livelihood and food security, but more dramatically lead to the collapse of Somalia administration stability [45].

Impact of RVF on Public Health (going beyond livestock production, marketing and trade)

Developing or transition countries which generally have limited public health systems are particularly at risk for zoonoses such as RVF. During a severe outbreak, extensive number of human infections could occur leading to substantial public health challenges in these countries [49]. Human deaths following RVF infection were first recorded during the epidemic of 1975 in South Africa when seven patients died of encephalitis and hemorrhagic fever associated with necrotic hepatitis [50]. In 1977-1978 a major RVF epidemic in Egypt resulted in 200000 human cases and 600 fatalities [51;52]. Twenty years later, a new epidemic affected over 500000 persons in East Africa, and 500 persons succumbed to the hemorrhagic form of the disease [7;53]. The recent outbreaks in 2006-2007 in Kenya, Tanzania and Somalia, and in 2007-2008 in Sudan as well as in Madagascar and South Africa in 2008-2009 resulted in thousands of human cases and hundreds of death (Table 2). As previously mentioned, humans may be contaminated by contact with virulent ruminant fluids such as blood. Thus RVF virus is a professional risk to laboratory workers, veterinarians, abattoir workers, butchers, livestock breeders; traders and shepherds [52]. The numbers of human deaths attributable to RVF are documented; it is nevertheless challenging to derive a financial value for human lives. Although some conventional techniques of insurance theory allow it to a certain extend. The outbreak of 2000-2001 of RVF in Saudi Arabia and Yemen resulted in the death of around 300 people and caused hundreds of infection [30]. The total cost calculated from the life insurance of those 300 human lives lost was estimated to be greater than 12 million USD [33]. However, the cost of hospital treatment for the hundred of cases was not accounted for in those calculations.

Direct costs linked to disease control measures

Direct control costs represent the value of all resources consumed which are associated with the management of the disease. They are generally well below the indirect costs of animal diseases and are directly linked to the rapid containment of outbreaks. Case studies have shown that early detection and the implementation of appropriate measures in the event of an outbreak are essential to help minimize direct losses as much as possible [16]. However, the implementation of control measures generally represents a significant financial investment [64]. Moreover, inappropriate implementation of such measures is often at the root of endemic situations which are much more difficult, and infinitely more costly, to resolve on the long run.

In the Arabic peninsula, due to the 2000-2001 RVF outbreak, the main importers of livestock from the Horn of Africa have started to take control and preventing measures such as a mass vaccination and vector eradication in the at risk zone. In Yemen, the total cost for the control of the RVF outbreak was estimated at more than 1 million USD by the international donors [65]. Nearly 50% of the expenses were on control measures (0.43 million USD) such as quarantine and serological monitoring of sentinel herds (0.13 million

USD) and vector population control using insecticide (0.3 million USD) (Table 3) [33]. Vaccination was not implemented in Yemen.

To contain the RVF outbreak in Saudi Arabia, a heavy control program was implemented. This programme included: vector control by land and aerial insecticide spray; 3 years animal movement restriction related to the vaccination and quarantine status of the animals; mass culling and burial of infected animals; mass vaccination followed with targeted vaccination (for animals older than 6 months) during and post-outbreak respectively (as a result, more than 10 million heads have been vaccinated); post-vaccination monitoring and serological surveillance (including sentinel animals) (with more than 16000 samples collected and analysed in three years) [62]. Although no estimated figures of the total cost of control measure in Saudi Arabia have been documented, the expenses to cover alone the vaccination of 10 million of animals are greater than 3 million USD. This only accounts for the price of the vaccine (0.3 USD/dose) and do not include the additional administration costs.

The government of Kenya invested more than 2.5 million USD to control the 2007 RVF outbreak [29]. Around 2.5 millions heads were vaccinated during the year of the outbreak (0.74 million USD) [66].

Vaccination during an outbreak under limited bio-security condition could represent an additional risk for amplification and spreading of the disease. The RVF infection could be in some cases asymptomatic (males) or the animals could be incubating the disease (no clinical signs). Vaccination teams may spread the infection through the use of multi-dose vials and the re-use of needles and syringes. Therefore caution must be taken when vaccination is implemented targeting animals in apparently disease-free areas adjacent to the outbreak especially in transhumant systems where space and time patterns are complex, as opposed to sedentary areas. This could end up being very costly and ineffective [67].

Therefore to avoid such heavy direct cost in importing countries, trading ban is one of the most systematic measure implemented to limit the risk of introduction of the disease from an infected country (e.g. Saudi Arabia enforced a five year ban on livestock imported from the Horn of Africa from 1997-2002). However, as seen above, such trade bans have an indirect economical impact on the exporting country which is often greater than any of the direct costs.

Short term versus Long term effect of the various impacts at various scales: the importance of the time horizon.

Animal diseases might also have indirect long term impacts, affecting deferred productivity. This is the case for RVF which affects the reproductive cycle (many abortions) and may therefore induce the reduction of the overall fertility rate of long-cycle species. The socio-economic impacts of the disease may last for a 10 to 20 years period before the livestock population is restored back to it normal status [27]. The long term costs of a slow response in terms of disease control are rarely taken into account.

Economic analyses focus primarily on the effects of the outbreaks and rarely take into account the long term effects of an endemic situation (characterized by less virulent outbreaks which re-occur for several years). With major crisis, measures of long-term impacts would make themselves unavoidably needed, since the additional costs of financing prevention and control measures would lead to an equivalent reduction in savings and investments.

Extending the measure of impacts of animal diseases to the tourism and leisure sectors could also be quite important. Because of the threat of indirect infection via mosquito bites during travel, tourists might cancel their visit. Indeed in Yemen the income revenue from the tourist industry in Yemen dropped by 30% in 2000 according to the official data which represents more than 30 million USD losses [33].

The effects on the environment must also be taken into account when wildlife is threatened, or in cases where the combating measures themselves have negative effects on the environment (such as the use of pesticides in the fight against vectors and in case of contaminated waste). Export bans can also lead to overstocking of livestock in production zones and large numbers of surplus sheep and goats result in overgrazing and environmental degradation, and depress the prices of animal in the local market therefore reducing the income and purchasing power of livestock owners.

DISCUSSION

Animal diseases are a major threat for farming economy [68]. Animals health economics is an important tool for decision makers with regards to the implementation of animals health intervention from local to international levels [69]. Recently, zoonotic animal diseases such as HPAI and SARS have affected the world’s economy with losses estimated in billions USD for HPAI worldwide and an economic impact equivalent to 2% of East Asian GDP for SARS [70].

In academic economic evaluation of health programs, comparing the costs of interventions and expected benefits between several intervention options is at the cornerstone and the aim of a full economic evaluation [71]. Full evaluation should be always privileged to support decision making. Literature review rather shows studies which in majority are partial economic evaluations, examining only the consequences or only the costs of disease(s) (impact study, or cost of illness) or control programme(s) (cost benefit; cost effectiveness). Nevertheless impact studies still remain of great importance to sensitize policy makers on the need for interventions and offer a way to compare the economical importance of several diseases.

Many outbreaks of RVF have been recorded since 1930 within different region of Africa and the Arabic Peninsula (Table 2). The global socio-economic impact from the societal perspective and linked to all these outbreaks is very difficult to estimate, though some estimates have been provided in some countries (Table 2). Many evidences show that RVF is one of the most threatening diseases for world livestock and more especially for the areas where the disease is recurrently appearing such as the Horn of Africa. In this region, livestock is the root for the economy and stability. The poorest people rely mostly on it for the fulfilment of basic nutrition and health care needs [72]. Since the first confirmed outbreak of RVF which occurred in Kenya in 1930, the socio-economic impacts of the disease in the Horn of Africa have been very significant. The local and/or international bans on the livestock trade which were enforced during each outbreak are responsible for most of this economical burden [15]. The enforcement of animal ban alone is not a sustainable control tool to reduce or prevent disease introduction; furthermore it always leads to dramatic socio-economic impacts, instability of the livestock industry and threat for the livelihood of pastoralist communities. Indeed, pastoralists account for 60% of the community in the Horn of Africa, one of the poorest region of the world [72].

In Yemen and Saudi Arabia the socio-economic impact was very high due to the losses of many human lives, market distortions and to the mortality and morbidity (abortion and decrease in milk production) in animals [11;12;73]. The outbreaks of 1997-1998; 2006-2007 and 2007-2008 in Sudan all occurred during the Eid Al-Adha period, a high peak period for exportation of livestock, exposing Sudan and importing countries to heavy economic consequences [63].

The introduction of the virus in the Arabic peninsula in 2000 opened up for a new era in the history of RVF. International organizations such as FAO, OIE, WHO, IAEA, CDC, USAID, and NASA paid a lot of attention to the improvement of veterinary services, quarantines and safer animal trade. Many workshops, conferences and training programs for diagnosis and surveillance of the disease have been conducted as well as the establishments of modern quarantines. In 2006, a modern animal quarantine was inaugurated in Djibouti for exportation of live animals to the Middle East and more especially to Saudi Arabia; another one is under construction in Berbera (Somalia) and a project for the extension of Al-Makah quarantine in Yemen is also ongoing. In addition the OIE programme for the evaluation of veterinary services and the twining programs between laboratories have led to the improvement of existing laboratories and of the veterinary services as regards to basic knowledge and precaution measures for early detection of RVF. Moreover, many research programs have been ongoing to improve knowledge on the epidemiology of the disease and to path the way for the development of efficient control measures. This enlightens the importance of the disease as an international threat and reinforces the need for wider economical impact studies to define the most sustainable control strategy.

The low standard infrastructure of quarantines in the region, the increase of illegal livestock trade, the limited capacity of laboratories and lack of exchange of information between the countries, have all lead to higher risk of re-introduction of RVF to Yemen and to others countries in the region with favourable ecosystems for the presence of the vectors. Late 2009 an epidemic started in South Africa with more than 13000 animal cases (11 June 2010) and 186 human cases (10 May 2010). This outbreak is still ongoing and animal cases are also being reported in Namibia since May 2010. The possibility of expansion to other regions like Europe and America could not be ruled out [2;4]. Early detection and the implementation of appropriate measures in the event of an outbreak would be essential to help minimizing its economic impact [16].

CONCLUSION

The impact of RVF in the Horn of Africa (Somalia, northeast of Kenya, Ethiopia and some parts of Djibouti) and in the Arabic Peninsula is of great importance regarding the degree of animal's trade and human movement in those areas. The Horn of Africa and the Middle East play also a considerable role in the world economy and stability. However, civil wars, poverty, draught, increase of human population and animal diseases leading to livestock trade bans have negative impact on the livelihood of the pastoralists. As a consequence, many of them are diverting to others activities that could result in political instability and international crises (e.g. terrorism from Somalia pirates in the Gulf of Aden).

Despite the dramatic economic impact of RVF on the livelihood of the pastoralists, few studies have been conducted on the assessment of the impact of the disease. One should emphasize the needs for such studies to be undertaken in a rapid time frame and with standardised methodologies to allow for comparison. A study conducted in Yemen demonstrated the importance of the economical impact of RVF when compared to other diseases even though this study was performed eight years after the epidemic in a completely different economical context [33].

The climatic change, humans movements, urbanization, extensive agricultural activities, demographic expansion and global animal trade has increased the threat from zoonotic disease and in particular the frequency and magnitude of vector born diseases such as RVF [74;75]. In order to reduce the socio-economic impact of this disease and to prevent its spread to unaffected areas, as well as to improve the living standards of the pastoralists, regional control and preventive measure should be put in place. This could include the set up of a regional surveillance network and early warning system, increasing the number of efficient quarantines as well as improving diagnostic capacities of the health care of the infected countries. Economical impact studies are critical to provide data to feed in cost-benefit analysis of interventions. Decision makers rely on this information to make strategic disease management choices.

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DECLARATION OF INTEREST

None.

REFERENCES

1. **Holleman C**. The Socio-economic Implications of the Livestock Ban in Somaliland. Nairobie, Kenya: United States Agency for International Development (USAID), 2002*;* FEWS NET IQC Famine Early Worning System Network publication no.**AOT-I-00-00-00142-00**.

2. **Bird BH, *et al*.** Rift Valley fever virus. *Journal of the American Veterinary Medical Association* 2009*;* **234**: 883-893.

3. **Swanepoel R, Coetzer JAW. Rift** Valley fever. In: Coetzer JAW; Thomson GR; Tustin RC, eds. *Infectious diseases of livestock with special reference to South Africa*. Cape Town: Oxford University Press, 1994; pp 688-717.

4. **Chevalier V, *et al*.** Rift Valley fever - a threat for Europe? *Eurosurveillance* 2010*;* **15**: 19506.

5. **Daubney R, Hudson JR, Garnham PC**. Enzootic hepatitis or Rift Valley fever: an undescribed disease of sheep, cattle and man from east Africa. *Journal of Pathology and Bacteriology* 1931*;* **89**: 545-579.

6. **Geering WA, Davies FG, Martin V**. Préparation des plans d'intervention contre la Fièvre de la Valley du Rift. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO), 2003; EMPRES publication. (FAO animal Health Manual; no. 15) (ftp://ftp.fao.org/docrep/fao/006/y4140f/y4140f00.pdf) Accessed June 2010.

7. **Davies FG, Martin V**. Recognizing Rift Valley fever. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO), 2003; EMPRES publication. (FAO animal Health Manual; no. 17).

8. **Davies FG, Martin V**. Recognizing Rift Valley Fever. *Veterinaria Italiana* 2006*;* **42**: 31-53.

9. **Davies FG**. Rift Valley fever in Yemen. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO), 2000.

10. **Madani TA, *et al*.** Rift Valley fever epidemic in Saudi Arabia: epidemiological, clinical, and laboratory characteristics. *Clinical Infectious Diseases* 2003*;* **37**: 1084-1092.

11. **Ahmad K**. More deaths from Rift Valley fever in Saudi Arabia and Yemen. *Lancet* 2000*;* **356**: 1422.

12. **Alquadasi M**. Rift Valley fever outbreak in Yemen Sep 2000/March 2001 and veterinary surveillance follow up. In : *Proceedings of the Rift Valley Fever Workshop : An integrated approach to controlling Rift Valley Fever (RVF) in Africa and the Middle East, 27-29 January 2009, Cairo, Egypt*. United States Department of Agriculture (http://www.ars.usda.gov/meetings/rvf2009/abstracts.htm). Accessed June 2010

13. **Ahrens JD**. Cessation of livestock exports severely affects the pastoralist economy of Somali Region. Addis-Ababa, Ethiopia: Addis-Ababa UNDP Emergency Unit for Ethiopia (EUE), 1998.

14. **Chevalier V, *et al*.** Epidemiological processes involved in the emergence of vector-borne diseases: West Nile fever, Rift Valley fever, Japanese encephalitis and Crimean-Congo haemorrhagic fever. *Revue Scientifique et Technique* 2004*;* **23**: 535-555.

15. **Davies FG, Nunn MJ**. Risks of Rift valley fever from livestock imported into the Kingdom of Saudi Arabia from the horn of Africa. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO), 1998*;* report no. **TCP/RAF/8821(E)**.

16. **Wanyoike F, Rich KM**. Socio-economic impacts of the 2007 Rift Valley fever outbreak in Kenya: a case study of the Northeastern province livestock marketing chain. Nairobie, Kenya: United State Agency for International Developement (USAID), 2007: International Livestock Research Institute (ILRI) publication.

17. **Alquadasi M**. Rift Valley fever (RVF) outbreak in Yemen, September 2000 - February 2001. In: *Proceedings of the 27th World Veterinary Congress, 25-29 September 2002, Tunis, Tunisa*.

18. **Meegan JM, Bailey CL**. Rift Valley fever. In: Monath TP, eds. *The Arboviruses: Epidemiology and Ecology IV*. Boca Raton, Florida: CRC Press Inc., 1989, pp. 51-76

19. **Meegan JM, Hoogstraal H, Moussa MI**. An epizootic of Rift Valley fever in Egypt in 1977. *Veterinary Records* 1979*;* **105**: 124-125.

20. **Swanepoel R, *et al*.** Comparative pathogenicity and antigenic cross-reactivity of Rift Valley fever and other African phleboviruses in sheep. *Journal of Hygiene (London)* 1986*;* **97**: 331-346.

21. **Kristjanson P, *et al*.** Pathways out of poverty in western Kenya and the role of livestock. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO), 2004*;* Pro-poor livestock policy initiative working paper **No.14**.

22. **Anon**. IAEA's support to animal health services in Yemen (1995-2009). Vienna, Austria: International Atomic Energy Agency (IAEA) and Food and Agriculture Organization of the United Nations (FAO): Joint FAO/IAEA programme publication. (http://www-naweb.iaea.org/nafa/aph/stories/2009-iaea-yemen.html). Accessed June 2010.

23. **McDermott JJ, Randolph TF, Staal SJ**. The economics of optimal health and productivity in smallholder livestock systems in developing countries. *Revue Scientifique et Technique* 1999*;* **18**: 399-424.

24. **Sansoucy R, *et al*.** Keynote paper: The contribution of livestock to food security and sustainable developement. In: Wilson RT, Ehui S, Mack S, eds. *Proceedings of the joint FAO/ILRI roundtable on livestock developement strategies for low income countries.* Nairobie, Kenya: FAO/ILRI, 2004. (http://www.fao.org/wairdocs/ILRI/x5462E/x5462e04.htm). Accessed June 2010.

25. **United States Agency for International Development**. Horn of Africa - Multi-sectorial interventions in pastoralist communities. Disaster Assistance publication, 2005. (http://www.usaid.gov/our_work/humanitarian_assistance/disaster_assistance/countries/horn_of_africa/mipc_index.html). Accessed June 2010

26. **United States Agency for International Development (USAID).** Brief report on the impact of Rift Valley fever in the Horn of Africa. *FewsNet* 2007 (http://www.fews.net/Pages/default.aspx). Accessed June 2010.

27. **Le Gall F**. Economic and social consequences of animal diseases. *Feed Tech* 2006*;* **10**: 17-20.

28. **Walter M, Tabitha K, Rwambo P**. The impact of Rift Valley fever on regional and international trade. In: World Animal Health Organization (OIE), eds. *Proceedings of the Workshop on RVF control and preventive strategies in the Middle East and the Great Horn of Africa: Rift Valley Fever control and preventive strategies.* Cairo, Egypt: World Animal Health Organization (OIE), 2007.

29. **Lichoti KJ**. Surveillance for RVF in Eastern Africa with reference to the outbreaks in Kenya and Tanzania. 2009. In : *Re-emergence of Rift Valley fever in Southern Africa : how to better predict and respond. Report of regional seminar, Bloemfontein, South Africa, 16-18 February 2009*. Paris, France : World Animal Health Organization (OIE), 2009.

30. **Sones K**. Making more of the Middle East market. *New Agriculturist* 2006. (http://www.new-ag.info/focus/focusItem.php?a=1160). Accessed June 2010.

31. **Stem C**. An economic analysis of the prevention of peste des petits ruminants in Nigerien goats. *Preventive Veterinary Medicine* 1993*;* **16**: 141-150.

32. **Anon.** Saudi Arabia: Cattle importer incur losses. *Al-Watan newspaper* 2001; 21 Mar.

33. **Handlos M.** Assessment of the estimated costs of past disease outbreaks in Yemen. Sana'a and Vientiane, Yemen: Rainfed Agriculture and Livestock Project: International expertise service for the General Directorate of Animal Resources, 2009; ICON-INSTITUT Public Sector GmbH and Jules van Lancker Consulting publication no **IDA CR. No. 4220 YEM**.

34. **Anon**. Zinga virus: a strain of Rift Valley fever virus. *MMWR Morbidity and Mortality Weekly Report* 1983*;* **32**: 90-92.

35. **United States Agency for International Development (USAID).** East Africa Regional Food Security Update: Rapid assessment of Garissa livestock market. *FewsNet* 2008 (http://www.fews.net/Pages/default.aspx). Accessed June 2010.

36. **Gaani MX, *et al*.** Regulating the livestock economy of Somaliland. Hargeysa, Somaliland: Academy for Peace and Development, 2002 (http://www.mbali.info/doc179.htm). Accessed June 2010

37. **Soumaré B, *et al*.** Effects of livestock import bans imposed by Saudi Arabia on Somaliland for sanitary reasons related to Rift Valley fever. *Outlook on Agriculture* 2006*;* **35**: 19-24.

38. **Aklilu Y, Irungu P, Reda A**. An audit of the livestock marketing status in Kenya, Ethiopia and Sudan (volume 1).Nairobie, Kenya: African Union/InterAfrican Bureau for Animal Resources (AU-IBAR), Pan-African program for the Control of Epizootics (PACE), 2002; Community Based Animal Health and Participatory Epidemiology unit publication.

39. **EMPRES Watch**. Rift valley fever could spread with movement of animals from East Africa. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO), 2008; Emergency Prevention Systems publication. (http://www.fao.org/docs/eims/upload/236966/EW_africa_dec07_rvf.pdf). Accessed June 2010.

40. **Anonymous**. Outbreak of Rift Valley fever--Yemen, August-October 2000. *MMWR Morbidity and Mortality Weekly Report* 2000*;* **49**: 1065-1066.

41. **Woods CW, *et al*.** An outbreak of Rift Valley fever in Northeastern Kenya, 1997-98. *Emerging Infectious Diseases* 2002*;* **8**: 138-144.

42. **United States Agency for International Development (USAID).** Horn of Africa food security update: Rift valley fever threatens livelihoods in the horn. *FewsNet*, 2000 (http://www.fews.net/Pages/default.aspx). Accessed June 2010.

43. **Anonymous**. Outbreak of Rift Valley fever--Saudi Arabia, August-October, 2000. *MMWR Morbidity and Mortality Weekly Report* 2000*;* **49**: 905-908.

44. **Anonymous**. Outbreak of Rift Valley fever--Yemen, August-October 2000. *MMWR Morbidity and Mortality Weekly Report* 2000*;* **49**: 1065-1066.

45. **Nin Pratt A, *et al*.** Benefits and costs of compliance of sanitary regulations in livestock markets: The case of Rift valley fever in the Somali region of Ethiopia. Nairobie, Kenya: International Livestock Research Institute (ILRI), 2005.

46. **Cagnolati V, Tempia S, Abdi AM**. Economic impact of Rift Valley fever on the somali livestock industry and a novel surveillance approach in nomadic pastoral systems. In: *Proceedings of the 11th Symposium of the International Society for Veterinary Epidemiology and Economics, Cairns, Australia*, Aug 2006, p 551. (http://www.sciquest.org.nz/node/64159). Accessed June 2010.

47. **Daubney R, Hudson JR, Garnham PC**. Enzootic hepatitis or Rift Valley fever: an undescribed disease of sheep, cattle and man from east Africa. *Journal of Pathology and Bacteriology* 1931*;* **89**: 545-579.

48. **Pinauldt G**. Epizooties et géographie du commerce du bétail dans la Corne d'Afrique. *EchoGéo* 2009*;* **8**.

49. **Labeaud AD, *et al*.** Interepidemic Rift Valley fever virus seropositivity, northeastern Kenya. *Emerging Infectious Diseases* 2008*;* **14**: 1240-1246.

50. **Gear JH**. Haemorrhagic fevers of Africa: an account of two recent outbreaks. *Journal of the South African Veterinary Association* 1977*;* **48**: 5-8.

51. **Imam IZ, Darwish MA, El-Karamany R**. An epidemic of Rift Valley fever in Egypt. 1. Diagnosis of Rift Valley fever in man. *Bulletin of the World Health Organization* 1979*;* **57**: 437-439.

52. **Meegan JM**. The Rift Valley fever epizootic in Egypt 1977-78. 1. Description of the epizzotic and virological studies. *Transactions of the Royal Society Tropical Medicine and Hygiene* 1979*;* **73**: 618-623.

53. **Anon**. Rift Valley Fever--East Africa, 1997-1998. *MMWR Morbidity and Mortality Weekly Report* 1998*;* **47**: 261-264.

54. **Shimshony A**. Disease prevention and preparedness in cases of animal health emergencies in the Middle East. *Revue Scientifique et Technique* 1999*;* **18**: 66-75.

55. **Peters CJ, *et al*.** Pathogenesis of viral hemorrhagic fevers: Rift Valley fever and Lassa fever contrasted. *Reviews of Infectious Diseases* 1989*;* **11 (Suppl 4)**: S743-S749.

56. **Shimshony A, Barzilai R**. Rift Valley fever. *Advances in Veterinary Science and Comparative Medicine* 1983*;* **27**: 347-425.

57. **Anon.** Rift Valley fever outbreak--Kenya, November 2006-January 2007. *MMWR Morbidity and Mortality Weekly Report* 2007*;* **56**: 73-76.

58. **Davies FG, Linthicum KJ, James AD**. Rainfall and epizootic Rift Valley fever. *Bulletin of the World Health Organization* 1985*;* **63**: 941-943.

59. **Gerdes GH**. Rift Valley fever. *Rev.Sci.Tech.* 2004*;* **23**: 613-623.

60. **Morvan J, *et al*.** First fatal human case of Rift Valley fever in Madagascar. *Transactions of the Royal Society Tropical Medicine and Hygiene* 1992*;* **86**: 320.

61. **World Animal Health Information Database (WAHID) Interface**. Rift Valley fever, Madagascar, 2008 (http://www.oie.int/wahis/public.php?page=single_report&pop=1&reportid=6637). Accessed June 2010

62. **Mohammed BNS**. Campaign for control of Rift Valley fever in Saudi Arabia. In: World Animal Health Organization (OIE), eds. *Proceedings of the Workshop on RVF control and preventive strategies in the Middle East and the Great Horn of Africa: Rift Valley Fever control and preventive strategies*. Cairo, Egypt: World Animal Health Organization (OIE), 2007.

63. **World Animal Health Information Database (WAHID) Interface**. Rift Valley fever, Sudan (http://www.oie.int/wahis/public.php?page=single_report&pop=1&reportid=6637 2007). Accessed June 2010

64. **Berentsen PBM, Dijkhuizen AA, Oskam AJ**. A dynamic model for cost-benefit analyses of foot-and-mouth disease control strategies. *Preventive Veterinary Medicine* 1992*;* **12**: 229-243.

65. **Anon**. Outbreak of Rift Valley fever--Yemen, August-October 2000. *MMWR Morbidity and Mortality Weekly Report* 2000*;* **49**: 1065-1066.

66. **ProMED-mail**. Rift Valley Fever-Easter Africa (21): Kenya, Vaccination. *ProMED-mail* 2007; 07 Mar: 20070307.0807 (http://www.promedmail.org). Accessed June 2010.

67. **Peyre M,** ***et al*****.** Avian influenza vaccination in Egypt: Limitations of the current strategy. *Journal of Molecular and Genetic Medicine* 2009*;* **3**: 198-204.

68. **Otte MJ, Nugent R, McLeod A**. Transboundary animal diseases: assessment of socio-economic impactys and institutionnal responses. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO), 2004; AGAL publication Livestock Policy Discussion Paper no**. 9**.

69. **Otte MJ, Chilonda P**. Animal health economics: an introduction. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO), 2000; AGAL publication.

70. **McLeod A,** ***et al*****.** Economic and social impacts of avian influenza. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO), 2008; Emergency Center for Transboundary Animal Diseases Operations (ECTAD) publication.

71. **Drummond MF,** ***et al*****.** Méthodes d'évaluation économique des programmes de santé; 2nd edn. Paris: Economica, 1998*;* pp.330.

72. **Knips V**. Revue of the livestock sector in the Horn of Africa (IGAD countries). Rome, Italy: Food and Agriculture Organization of the United Nations (FAO), 2004; Livestock Information AGAL publication (http://www.fao.org/ag/againfo/resources/en/publications/sector_reports/lsr_IGAD.pdf). Accessed June 2010.

73. **Al-Hazmi M,** ***et al*****.** Epidemic Rift Valley fever in Saudi Arabia: a clinical study of severe illness in humans. *Clinical Infectious Diseases* 2003*;* **36**: 245-252.

74. **Bouloy M, Flick R**. Reverse genetics technology for Rift Valley fever virus: current and future applications for the development of therapeutics and vaccines. *Antiviral Research* 2009*;* **84**: 101-118.

75. **Flick R, Bouloy M**. Rift Valley fever virus. *Current Molecular Medicine* 2005*;* **5**: 827-834.

TABLES

Table 1. *Clinical impact of RVF in livestock*

Susceptible species	**Syndromes**	**Abortion rate**	**Death rate**		**Comments**	**Ref**
			Adults	**Neonates**		
(<1 month)						
Sheep	Febrile response, lethargy; hematemasis, nasal discharge	90-100%	10-30%	90-100%	-	[2;12]
Cattle	lachrymation, salivation and dysgalactia	90-100%	5-10%	10-70%	Reduction in milk production in lactating cows	[2;12; 26;47]
Goat	Febrile, anorexia, weakness, listlessness, mucopurulent nasal discharge, foetid diarrhoea,					
Increased respiratory	90-100%	More resistant (70% seroconversion following epizootie)	48%	Refractory to severe or lethal disease than sheep		[2]
Camel	In apparent infection, brief viraemia and Abortion	90-100%	3% seroconversion	20%	-Death does occur in the early post-natal period.	[2]

Table 2. *Main Rift Valley Fever outbreaks from 1930- 2009 (non exhaustive list): animal, human health and global economical estimated costs*

Country (outbreak period)	**Animal cases (mortality)**	**Human cases Estimated**	**Reported (fatalities)**	**Estimated economic impact in million USD (% GDP(PPP)**	**Comments and References**
Egypt (1977-78)	No report	-	200000 (594)	115 (0.8%)	Largest human infection in the history deaths and abortions of sheep, cattle and some losses in water buffaloes and camels [52;54-56]
Kenya (2006-2007)	4000 (230)	75000	684 (234)	50 (0.1%)	[29;47;57;58]
Kenya Somalia (1997-1998)	1,5 million (600 000)	-	89000 (250)	76 (1.4%) 110 (2.1%)	[1;59] Somalia producer income losses due to the ban 1998/99 Somalia livestock income losses due to ban in 1998/99
Madagascar (2007-2008) (2009)	2 (0) 22 (18)	10000 2500	418 (17) 233 (4)	- -	[60;61]

Saudi Arabia (2000-2001)	40000 (11000)	-	886 (123)	-	[11;62]
Somalia (2006-2007)	No report	30000	114 (51)	145 (2.7%)	Producers losses 326 (2.8%) Somalia livestock income losses 2 years market ban (2000-2002) [1]
Sudan (2008)	No report	75000	738 (230)	-	[63]
Tanzania (2006-2007)	32000 (4800)	-	264 (109)	-	[29]
Yemen (2000-2001)	22000 (6600)	-	1080 (140)	107 (0.8%)	[11;33]
Zimbabwe (1978)	60000 (10000)	30% cattle infected in outbreak zone	-	-	No human cases officially reported [3]

- No information; USD, United States Dollar; GDP (PPP), gross domestic product at purchasing power parity per capita

Note: this list is a non-exhaustive list and complete information on RVF outbreaks could be found on WAHID (OIE Animal Health Information database) at http://www.oie.int/wahis/public.php.

Table 3. *Estimated economic impact of RVF outbreak in Yemen in 2000-2001* [33]

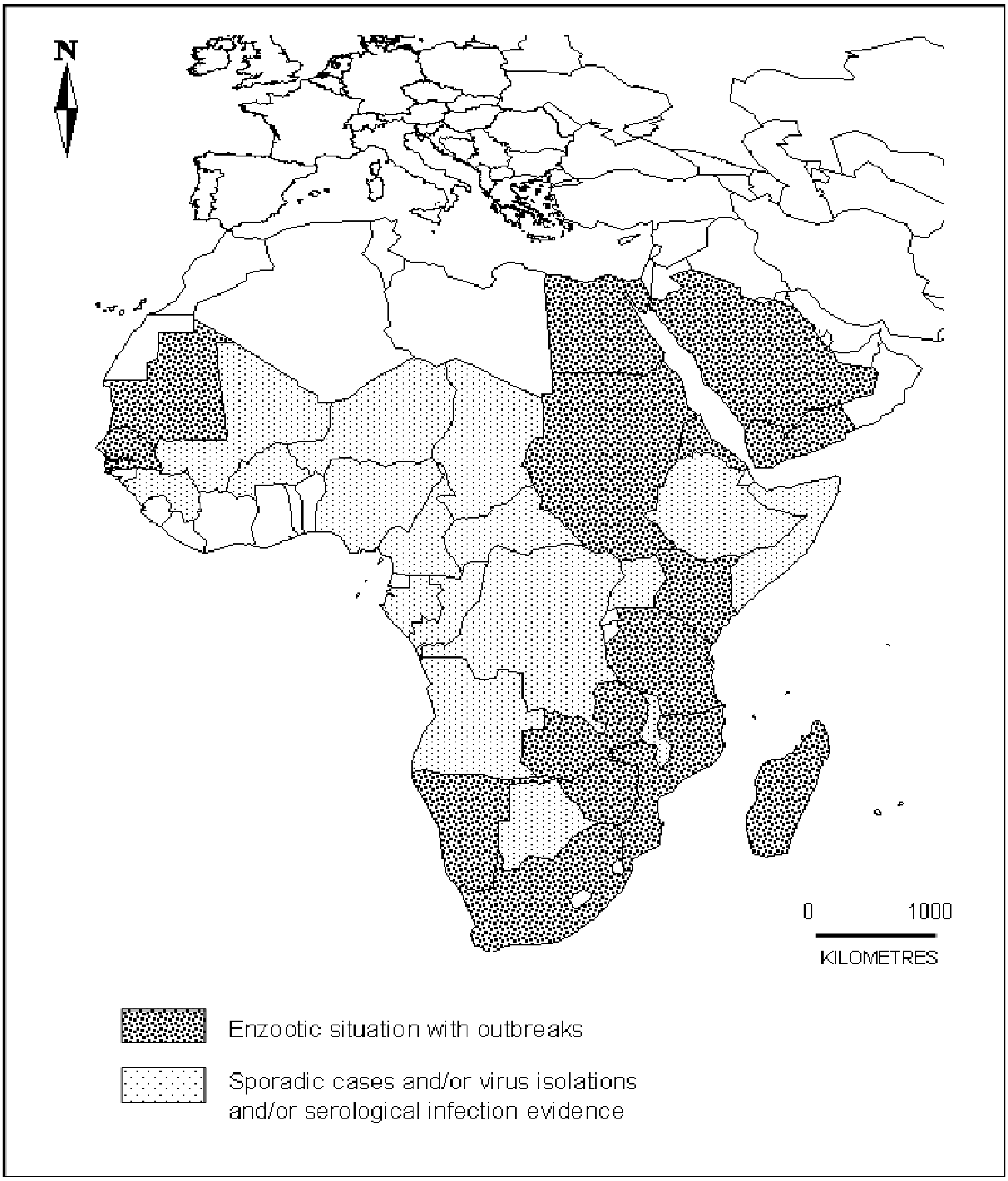
Sector	**Losses (in million USD)**	**% annual GDP (PPP)***
Trading	50	0.4
Livestock industry	15	0.1
Vector Control	0.3	0.002
Public health (death only)	12	0.1
Tourism	30	0.2
Total	***107.3***	***0.8***

USD, United States Dollar; GDP (PPP), gross domestic product at purchasing power parity per capita

*mean annual GDP (PPP) between 2000-2003 = 14000 million USD; for information: total exports= 4.5% annual GDP (PPP); total imports= 5.6% annual GDP (PPP)

Figure Legend

Figure1: Geographical distribution of Rift Valley fever



Adapted from Chevalier et al. [4] Available on line:

http://www.eurosurveillance.org/ViewArticle.aspx?ArticleId=19506.

Figure 2. Geographical localisation of main and local markets on the east costs of the Horn of Africa and the southern costs of the Arabic Peninsula. This map illustrates the commercial proximity between the two regions.

Source: Marie Gely, CIRAD, 2010.

Part II: Research studies on the epidemiology of Rift Valley Fever in Yemen and the risk of re-introduction from the Horn of Africa

The specific objectives of this section are:

A - To provide a descriptive study of the epidemiology of the RVF in Yemen at local and national level in relation to the ecological and climatic factors and to the system of surveillance and control.

In order to describe RVF patterns in Yemen and explore the possible role of climatic and environmental factors, a study was conducted at a local scale in Yemen in a 30 km radius area located in the coastal plain of the Tihama region. The results of this first study are presented in **Chapter 4**.

The main risk factors associated to RVF outbreaks, e.g. data on altitude, rainfall, flood, and NDVI, were later collected and pre-processed in order to integrate epidemiological and environmental data for analysis.

It appears that since 2001, no other outbreak was declared in Yemen (Al Qadasi 2009). Thus, considering the whole Tihama Coast, a descriptive analysis of the recent period (1999-2007) was conducted **(Chapter 5)**. It included environmental and socio-economic factors likely to have been involved in RVF emergence in Yemen in 2000. Each year was characterized by environmental conditions (linked to vegetation indexes), festival calendar and economic data. A Principal Component Analysis was performed to synthesize the different variables, assess whether the year 2000 was atypical compared to the other years of the 1999-2007 period, and if yes, to which respects.

B- To assess the risk of re-introduction of RVF from the Horn of Africa through legal importation of livestock assuming the virus has not survived in Yemen after 2001

Data from field studies and literature were collected to qualitatively assess the likelihood of “re-introduction” of RVF into Yemen through the legal importation of small ruminants from the Horn of Africa **(Chapter 6)**. After precisely describing the routes and volume of trade from the Horn of Africa to Yemen, the pathway and different scenarios for introduction were developed following the OIE risk assessment method. A matrix of likelihood combinations including four possible levels (very low, low, medium, high) was built and used to combine likelihood of events.

The studies of this Part II are presented as articles which are either published, submitted or in preparation:

Chapter 4:

Abdo-Salem S., Gerbier G., Bonnet P., Al-Qadasi M., Tran A., Al-Eryani G., Roger F**.** 2006. Descriptive and spatial epidemiology of Rift valley fever outbreak in Yemen 2000-2001. Annals of the New York Academy of Sciences, 1081: 240-242.

Chapter 5:

Abdo-Salem S., Tran A., Grosbois V., Gerbier G., Al-Qadasi M., Saeed K., Etter E., Thiry E., Roger F., Chevalier V. Can environmental and socio-economic factors explain the recent emergence of Rift Valley Fever in Yemen, 2000-2001? To journal of Vector Borne and Zoonotic Diseases (accepted)

Chapter 6:

Abdo-Salem S., Waret-Szkuta A., Roger F., Olive M-M, Saeed K., Chevalier V. 2010. Risk assessment of the introduction of Rift Valley Fever from the Horn of Africa to Yemen via legal trade of small ruminants. Tropical Animal Health and Production 2010; published online http://dx.doi.org/10.1007/s11250-010-9719-7

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Chapter 4: Descriptive and spatial Epidemiology of Rift Valley Fever outbreak in Yemen 2000-2001

In order to describe RVF patterns in Yemen and explore the possible role of climatic and environmental factors, a study was conducted at a local scale in Yemen in a 30 km radius area located in the coastal plain of the Tihama region. This region was the most affected area during the 2000 RVF outbreak. RVF cases data were collected during the 2000-2001 epidemics by the Yemeni vet services.

Descriptive and Spatial Epidemiology of Rift Valley Fever Outbreak in Yemen 2000–2001

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ABSTRACT: Rift valley fever (RVF) is an arboviral disease produced by a bunyavirus belonging to the genus Phlebovirus. Several species of *Aedes* and *Culex* are the vectors of this virus that affects sheep, goats, buffalos, cattle, camels and human beings. The human disease is well known, especially during periods of intense epizootic activity. The initial description of the disease dates back to 1930, when animals and human outbreaks appeared on a farm in Lake Naivasha, in the Great Rift Valley of Kenya. Until 2000, this disease was only described in Africa, and then outbreaks were also declared in the Kingdom of Saudi Arabia (2000–2001 and 2004) and in Yemen (2000–2001). Animal and human cases were recorded. This work presents a retrospective summary of the data collected on animal RVF cases during this epidemic in Yemen. Results from several RVF surveys were gathered from the Yemeni vet services and FAO experts. Geographical data (topographic maps and data freely available on internet) were used for the location of outbreaks. After cleaning and standardization of location names, all the data were introduced into a GIS database. The spatial distribution of outbreaks was then studied at two scales: at the national level and at a local scale in the particular area of Wadi Mawr in the Tihama plain, Western coast of Yemen.

KEYWORDS: Rift valley fever; Yemen; vector-borne disease; zoonosis

INTRODUCTION

Rift valley fever (RVF) is an arboviral disease produced by Bunyavirus belonging to the genus Phlebovirus. Several species of *Aedes* and *Culex*

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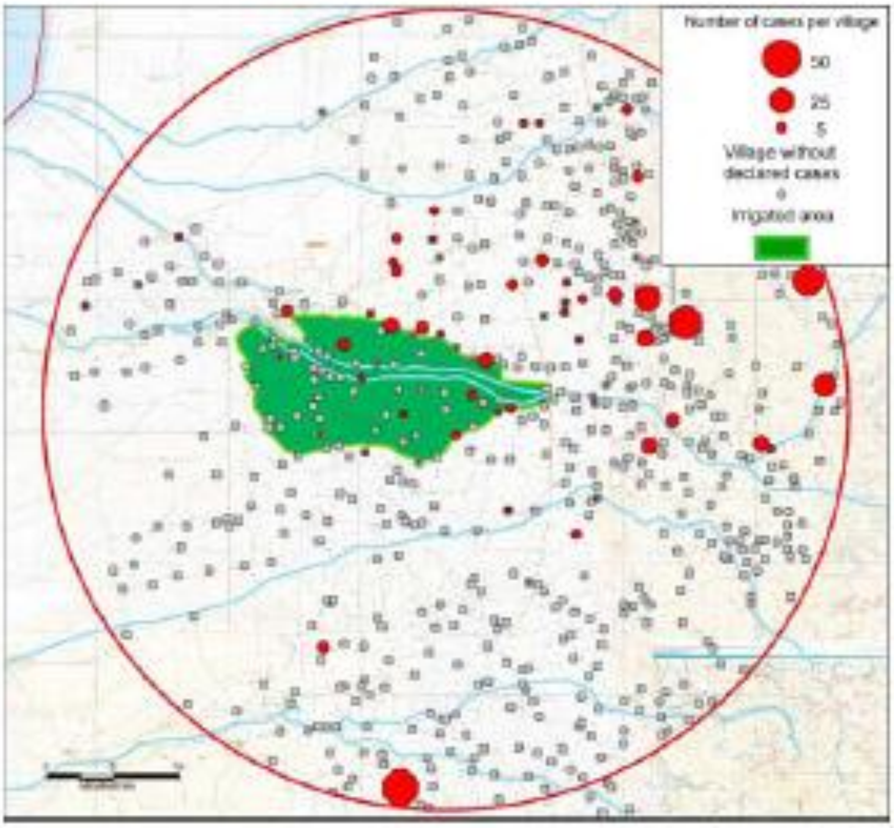

FIGURE 1. Villages infected around Bajilah from September 23, 2000 to February 3, 2001.

mosquitoes are the vectors of this virus, which not only affects sheep, goat, buffalo, cattle, and camels but also human beings. The human disease is well known, especially during the period of intense epizootic activity. Until 2000 this disease was only described in Africa; then outbreaks were declared for the first time outside Africa,[1,2] in the Kingdom of Saudi Arabia (2000–2001 and 2004) and in Yemen (2000–2001); animal and human cases were recorded. This work presents a retrospective summary of the data collected on animal RVF during the epidemics in Yemen.

METHODS

Results from several surveys were gathered and standardized from Yemen epidemiology unit Sana'a and FAO experts. The data used were from September 23, 2000 to February 3, 2001. An RVF case was defined as a village with at least one death or abortion in cattle, sheep, goat, or camel during this period. A 30 km radius area around the village of Bajilah was chosen in the Wadi Mawr (coast of Tihama). This intersects the districts of Az-Zuhrah, Al-Qanawis, Al-Luhayah, Az-Zaydiyah in the Governorates of Al-Hodeidah, Al-Tur, Kuaydinah, and Abs in Hajjah. In this area, 612 villages were pointed on 1:50,000 scale paper maps and compared with the epidemiological data set.

RESULTS AND DISCUSSION

Out of these villages, 67 were found infected with the RVF (FIG. 1). Most of these villages were located around the irrigation canal Wadi Mawr. The analyses of the precipitation data in the three meteorological stations (Az-Zuhrah, Kadamat Malaryah, and Jabal Al-Malah) from 1975 to 2002, showed no significant difference. No countrywide entomological studies were conducted nor were sentinel herds set up during the epidemics.[3] A first interpretation of a vegetation index derived from satellite imagery (NDVI: normalized difference vegetation index) showed a spatial heterogeneity in the cases location but no significant difference between the years 1999 and 2000. In the future the passive surveillance should be continued and quality of data should be improved. Landscape studies and entomology surveys in the area should be performed.

REFERENCES

1. ANONYMOUS. 2000. Outbreak of Rift Valley fever-Yemen, August-October 2000. MMWR Morb. Mortal Wkly Rep. 49: 1065–1066.
2. WORLD ORGANIZATION ANIMAL HEALTH. 2004. Rift Valley fever in Saudia Arabia—serological findings. OIE Disease information. 17: 40.
3. LINTHICUM, K.J., C.L. BAILEY, *et al*. 1987. Detection of Rift Valley fever viral activity in Kenya by satellite remote sensing imagery. Science 235: 1656–1659.

Chapter 5: Can environmental and socio-economic factors explain the recent emergence of Rift Valley Fever in Yemen, 2000-2001?

(Article accepted in Vector Borne and Zoonotic Diseases)

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Can Environmental and Socioeconomic Factors Explain the Recent Emergence of Rift Valley Fever in Yemen, 2000–2001?

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Abstract

Rift Valley fever (RVF) is a major vector-borne zoonosis first identified on the African continent in the early 1900s. In 2000, RVF was reported for the first time in Yemen. In this study, we provide a descriptive analysis of the period 1999–2007 in Yemen, taking into account the environmental and socioeconomic factors likely to have been involved in the emergence of RVF in the country. We characterize each year in the study period by the environmental conditions (linked to vegetation indexes), the festival calendar, and economic data. We then use a principal component analysis to synthesize the different variables, assess whether the year 2000 was atypical compared with other years in the study period, and, if that was the case, in what respect. Our results show that 2000 presented above-normal vegetation index values, which reflect important precipitation, for both the two rainy seasons (the first between March and May; the second between July and October). These environmental conditions, ones favorable to mosquito vector populations, coincided that year with a late (March) starting date of the Eid al-Kabeer festival, which corresponds to a period with high host (cattle, sheep, goats) densities. According to these criteria, 2000 was an atypical year. These conclusions suggest that it is important to consider social variables in addition to environmental ones when assessing the risk of RVF emergence.

Key Words: Emergence—Rift Valley fever—Socioeconomic factors—Vegetation index—Yemen.

Introduction

Rift Valley fever virus (RVFV), a member of the *Phlebovirus* genus (family Bunyaviridae), causes RVF, a major vector-borne zoonosis that has afflicted the African continent since the early 1900s (Swanepoel and Coetzer 1994, Gerdes 2004). The main vectors are mosquitoes, mainly from *Aedes* and *Culex* genera. The bioecology of these two mosquito genera is different and both species probably contribute to the epidemiological cycle of the disease in different ways. *Aedes* females lay their eggs on the mud of temporary water points. The eggs can survive for several years in desiccated mud if the water point dries up (Linthicum et al. 1985, O'Malley 1990). To hatch, the eggs must first dry out for a minimum of several days before being submerged in water. Fluctuations of water level are consequently necessary for *Aedes* populations to develop. In contrast, *Culex* eggs do not survive desiccation; *Culex* populations therefore need the permanent presence of water to develop.

The virus also may be transmitted, to both ruminants and humans, by direct contact with viremic body fluids such as blood (during slaughtering and butchering), fetal membranes, and amniotic liquid of viremic ruminants. Most human cases are relatively mild and of short duration (WHO 2007). However, complications such as retinitis, encephalitis, and hemorrhagic disease occur in a small proportion of patients, with significant fatality rates. When there is an outbreak in livestock, mortality and abortions have a direct economic impact. However, the indirect impact of outbreaks are even greater as, in accordance with international sanitary policies, very strict restrictions of livestock movement and embargoes on the exportation of live animals and animal

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products are imposed when cases of infection are declared (Davies 2006).

Prior to 2000, RVF had been only reported in the African continent. Yemen officially declared the first outbreak of RVF on September 19, 2000 (CDC 2000a), a few days after RVF cases were declared in Saudi Arabia (CDC 2000b). This outbreak started on the Tihama Coast (Az-Zuhrah district, Al-Hodeidah governorate) and led to a total of 1328 human cases (166 deaths) (WHO 2000), more than 21,000 animal abortion cases, and 6000 animal deaths between September 2000 and February 2001 (Ahmad 2000, Al Qadasi 2002). This Tihama region was the most affected area during this outbreak (Abdo-Salem et al. 2006). Then, since 2001, no significant RVFV activity has been reported in Yemen (Al Qadasi 2009).

A conjunction of favorable socioeconomic and environmental factors could have contributed to the emergence of RVF in Yemen. First, a large part of the live animals imported into the Arabian Peninsula are originating from RVF endemic areas in the Horn of Africa, where a severe outbreak occurred in 1997–1998 (Woods et al. 2002). The RVFV thus may have been introduced into Yemen through livestock trade with this region (Davies 2000). This hypothesis is supported by genetic analyses of the virus isolated in Saudi Arabia and Yemen showing similarity with the strain that circulated in Kenya (1997) (Shoemaker et al. 2002). Second, unusual rainfall and subsequent flooding of mosquito habitat have been associated with RVF outbreak in the Horn of Africa (Linthicum et al. 1999). It has been shown that satellite-derived measurements of photosynthetic activity (vegetation index), combined with other climatic variables, can efficiently monitor the outbreaks in the East of Africa (Anyamba et al. 2006b, 2007, 2009). However, in 2006, the occurrence of bioclimatic conditions potentially at risk for RVF (Anyamba et al. 2006a) was not followed by any sign of RVFV circulation in Yemen, suggesting that several drivers modulate the emergence of such a complex disease.

To assess the contribution of both socioeconomic and environmental factors in the recent emergence of RVF in Yemen, we explored in detail the period 1999–2007 and described each year in terms of bioclimatic conditions and related activity of the vegetation, trade statistics, and main calendar events driving livestock trade, more specifically religious festival (Eid al-Kabeer celebrations).

Two different potential scenarios were considered (Davies 2000, Swanepoel and Coetzer 2004):

(1) The RVFV was present in Yemen prior to 2000 (possibly introduced from the Horn of Africa during the 1997–1998 outbreak) and the environmental conditions in 2000 favored the amplification of the RVF cycle by mosquito vector populations, leading to an important outbreak in September 2000 (scenario 1);

(2) The RVFV was not present in Yemen prior to 2000, and the association of environmental and socioeconomic conditions in 2000 supported both the introduction and amplification of the virus (scenario 2).

Materials and Methods

Study area

The study area was conducted in the coastal plain of Tihama, in the western part of Yemen (Fig. 1). This area lies

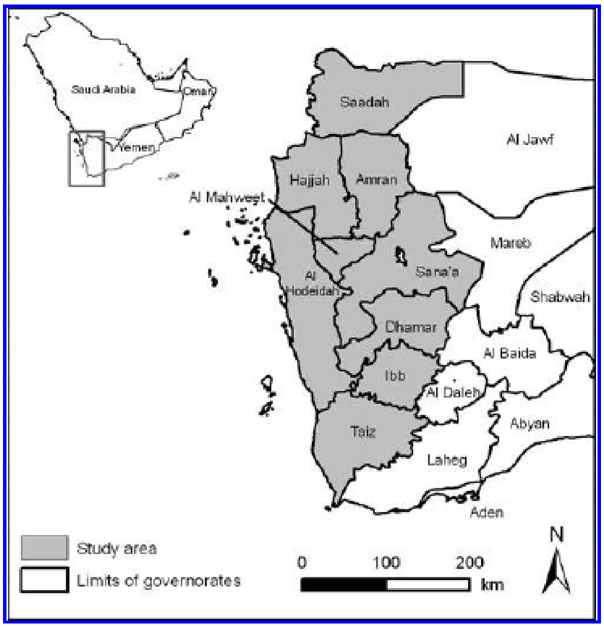

FIG. 1. Location of the study area, Tihama coast, Yemen.

parallel to the Red Sea and is bordered by the Kingdom of Saudi Arabia in the north, the Red Sea and the strait of Bab el-Mandeb in the west, and the mountains of Tihama in the east (Tihama Development Authority 1987). The area includes nine governorates: Sa'dah, Hajjah, Amran, Al-Hodeidah, Al-Mahweet, Sana'a, Dhamar, Ibb, and Taiz. Of these, three (Sa'dah, Hajjah, and Al-Hodeidah) were affected during the 2000–2001 outbreak (Abdo-Salem et al. 2006).

In this semiarid region, the climate is dry and hot with temperatures ranging from 30°C–35°C in summer to 25°C–28°C in winter. The relative humidity ranges from 55% to 70%. The mean annual rainfall varies from 50 to 350 mm/year for the whole Tihama region, with two rainy seasons: the first between March and May (accounting for 25% of the total annual rainfall) and the second from July to mid-October. The area is characterized by drainage courses known as "Wadis," a spate irrigation management system widely used in semiarid environments (Noman 2005). Every rainy season, flood waters from mountain catchments are diverted from river beds and spread over large areas for irrigated agriculture (Chevalier et al. 2008). This irrigation system favors the hatching of *Aedes* populations, which are possible vectors of RVFV. Additionally, artificial water ponds maintained year round for agriculture allow other mosquito species, including *Culex* populations, to persist throughout the year.

Environmental data

We choose satellite-derived measurements of normalized difference vegetation index (NDVI), related to vegetation activity, to characterize the environmental conditions of each year in the 1999–2007 study period. This variable is assumed to be linked with rainfall events and thus to indicate favorable conditions for the proliferation of mosquitoes in flooded areas. Rainfall data were not used because, in the Tihama Coast, hydrological dynamics is essentially due to runoff from the mountainous areas. Previous studies highlighted the link between high NDVI anomalies and RVF in the Horn of Africa (Linthicum et al.1999, Anyamba et al. 2007, 2009). Here, we characterized for each year of the 1999–2007 period the shape of the temporal dynamics of NDVI.

The NDVI is a vegetation index (values ranging from −1 to 1) linked to photosynthetic activity (for example, see Fig. 2a). In arid areas, the NDVI has been shown to be a good proxy for rainfall because in such areas vegetation grows very quick after shower (Davenport and Nicholson 1993, Nicholson and Farrar 1994, Haas et al. 2009, Soti et al. 2009).

Satellite Pour l'Observation de la Terre (SPOT)-Vegetation images (see www.spot-vegetation.com/), which allow daily monitoring of terrestrial vegetation cover, were processed to calculate for each year and each month the mean NDVI value over the study area. From these NDVI time series, different characteristics were extracted for each year (Fig. 2b):

- The maximum value of NDVI observed per rainy season ($NDVI.Peak_{1,2}$).
- The width of the main rainy season peak, defined as the duration (in months) of the period with NDVI above at 90% of the maximal value (NDVI.width).
- The dates of the maximum of NDVI value during each rainy season ($NDVI.Date_{1,2}$).

The first two variables were likely to be associated with high mosquito population densities (amount of precipitation, duration of the rainy season), and the third variable (dates of peak occurrences) was used to assess the possible overlapping of the periods with high mosquito densities with the dates of festival celebrations, which correspond to periods of high host population densities in the considered area.

Socioeconomic data

As the RVFV might have been introduced into Yemen by the importation of viremic animals from the Horn of Africa, the total number of animals (sheep, goats, and cattle) imported per year in Yemen was used as an indicator of the risk of virus introduction into this region (data collected from Yemen Quarantine Authority, Sana'a). The three main Yemeni quarantine facilities are in Al-Mukah, Al-Mukhalla, and Aden. Most of the imported livestock originates from eastern Kenya and Ethiopia and transits via local Somalia markets (Alary 2006, Fleming et al. 2008). The numbers of cattle and small ruminants imported vary substantially over and between the year, peaking just before the religious festivals of Ramadan and Eid al-Kabeer (Fleming et al. 2008), when millions of animals (sheep, goats, and bulls) are sacrificed. If this event takes place during periods of high vector densities, it consequently may be of importance for both the introduction of the RVFV and its amplification (Davis 2006). The starting date of Eid al-Kabeer was then considered for each year, as it varies depending on the Islamic lunar calendar, with a drift backward every year by 10–12 days in relation to the solar-based Gregorian calendar. The dates of Ramadan were not separately considered as they are directly derived from Eid al-Kabeer (Eid al-Kabeer takes place 3 months and 10 days after the first day of Ramadan).

Statistical analysis

Two runs of principal component analysis (PCA) were carried out to generate integrative descriptions of the different years under study (1999–2007). A PCA transforms a number of variables with possible redundancy into a smaller number of uncorrelated variables named principal components (PCs) or axes. The first analysis used only environmental factors likely to impact abundant vectors populations ($NDVI.Peak_{1,2}$, NDVI.width) and thus cycle amplification by vector populations (scenario 1). The second analysis simultaneously included the environmental, economic (statistics on livestock imports), and social (festival calendar) factors likely to favor virus introduction and

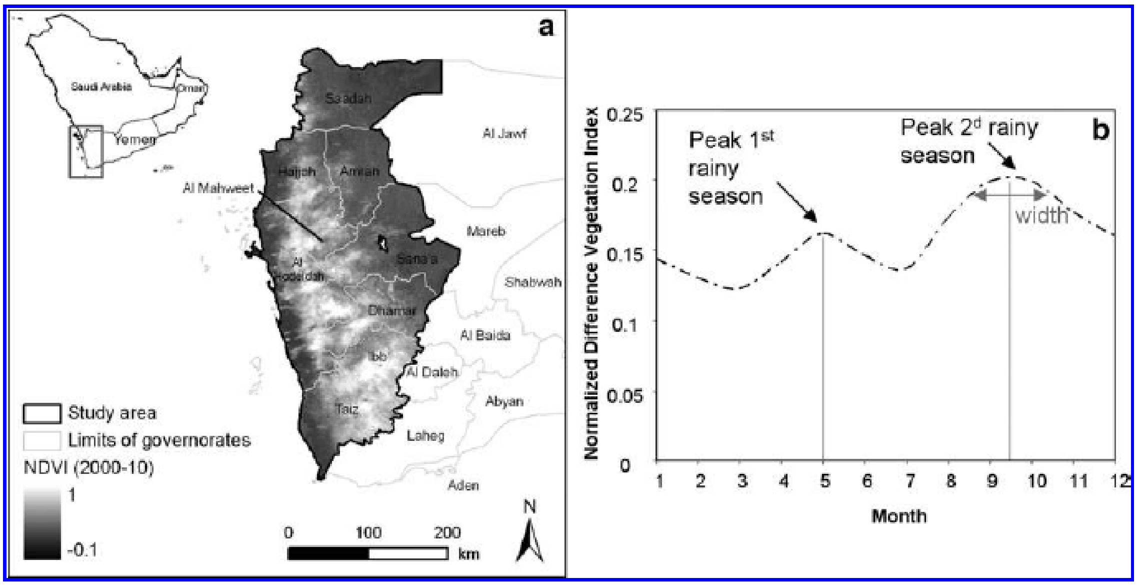

FIG. 2. Normalized difference vegetation index (NDVI) image, Tihama coast, Yemen, October 2000 **(a)**, and characteristics extracted from temporal series of monthly NDVI values averaged on the study area **(b)**. Data source: Centre National d'Etudes Spatiale (CNES), France; distribution: Vito, Belgium (http://free.vgt.vito.be/).

Table 1. Environmental and Socioeconomic Variables Used to Characterize Each Year from 1999 to 2007, Yemen

	Vegetation index variables						
	Date of the NDVI peak (month)*		*Maximum of NDVI*		*Width of the second rainy season peak (month)*	*Socioeconomic variables*	
Year	*First rainy season*	*Second rainy season*	*First rainy season*	*Second rainy season*		*Number of imported animals*	*Starting date of Eid al-Kabeer*
1999	4	10	0.16	0.22	2.1	757,675	March 28
2000	5	10	0.17	0.22	0.8	250,505	March 17
2001	5	9	0.17	0.22	1.0	47,625	March 6
2002	5	9	0.17	0.21	0.6	611,427	March 2
2003	5	10	0.15	0.18	1.4	683,682	February 12
2004	5	10	0.16	0.19	0.4	892,964	February 1
2005	5	9	0.16	0.19	1.6	1099,647	January 21
2006	5	9	0.16	0.22	0.6	1069,812	January 11
2007	4	8	0.17	0.20	1.5	808,122	January 1

*NDVI, normalized difference vegetation index.

amplification due to the conjunction of high livestock densities during the religious festivals and abundant vector populations (scenario 2).

Results

At first glance, the year 2000, when the RVF outbreak was declared in Yemen for the first time, does not differ from other years in the study period (1999–2007) (Table 1). Dates of NDVI peaks were relatively late (May and October) in 2000, as in 2003 and 2004. The maximum values of NDVI were high in both rainy seasons in 1999, 2000, and 2001. The second rainy season lasted not very long in 2000, compared with 1999, 2003, or 2005. The number of imported animals varied between 1999 and 2007: it dropped down in the 2000–2001 period because of the embargo (September 2000–mid 2002) following the RVF outbreak in Yemen; then it rapidly increased again. Starting dates of the Eid al-Kabeer celebrations ranged from the 1st of January to the end of March, for the period under study.

Three PCs were obtained from the first PCA, which included only environmental factors linked to vector abundance (Table 2). The first two PCs contribute to 88% of the variance observed (Table 2). The first PC is mainly linked to the NDVI peaks: it takes positive values for years with high first and second NDVI peaks, whereas negative values are associated with low values of both NDVI peaks. The second PC is mainly linked to the width of the second NDVI peak: it takes positive values for years with a narrow second NDVI peak, and negative values for years with a wide second NDVI peak.

When the years 1999–2007 are plotted in the space formed by these first two PCs (Fig. 3a), and the vegetation index NDVI is used as a proxy for rainfall and thus favorable conditions for mosquito development, the years 1999, 2000, 2001, 2002, 2006, and 2007 all emerge as years at risk for RVF amplification, with either high maximum values of NDVI peaks or a long second rainy season (values are presented in Table 1). Thus, it can be preliminarily concluded from the first PCA that when bioclimatic variables only are taken into account, the year 2000 should not be considered as contrasted compared with other years under study.

The second PCA, which included environmental, economic, and sociocultural factors, highlighted a more differentiated pattern (Fig. 3b). Six axes were needed to capture all the variance, the first two representing 61% of the variance (Table 3). The first PC is built as a combination of environmental and socioeconomic factors: it takes positive values for years with high values of the NDVI peaks, low imports, and a relatively "late" Eid al-Kabeer, for example, one coinciding with the start of the spring rainy season in March, whereas negative values are associated with low values of NDVI peaks, high imports, and an "early" (January) Eid al-Kabeer (Fig. 3b). The second PC is mainly linked to the dates of the NDVI peaks: it takes positive values for years with late first and second NDVI peaks, and negative values for years with early first and second NDVI peaks.

The main characteristics of the year 2000 with positive coordinates for the two first PCs were the conjunction of late NDVI peaks, high NDVI peaks, a "late" Eid al-Kabeer, and a relatively low number of imported animals. In the PCA first plan, formed by PC1 and PC2, 2000 individualizes from the other years with projection in positive values for the two first axes (Fig. 3b).

Table 2. Results of the Principal Component Analysis: Rotated Factor Matrix and Proportion of Variance—Three Environmental Variables, Yemen, 1999–2007

Variables	*Notation*	*PC1*	*PC2*	*PC3*
Maximum of NDVI, first rainy season	NDVI.Peak1	0.69	−0.06	0.72
Maximum of NDVI, second rainy season	NDVI.Peak2	0.63	−0.44	−0.64
Width of the second rainy season peak	NDVI.Width	−0.36	−0.90	0.26
Proportion of variance		0.56	0.32	0.13
Cumulative proportion of variance		0.56	0.88	1

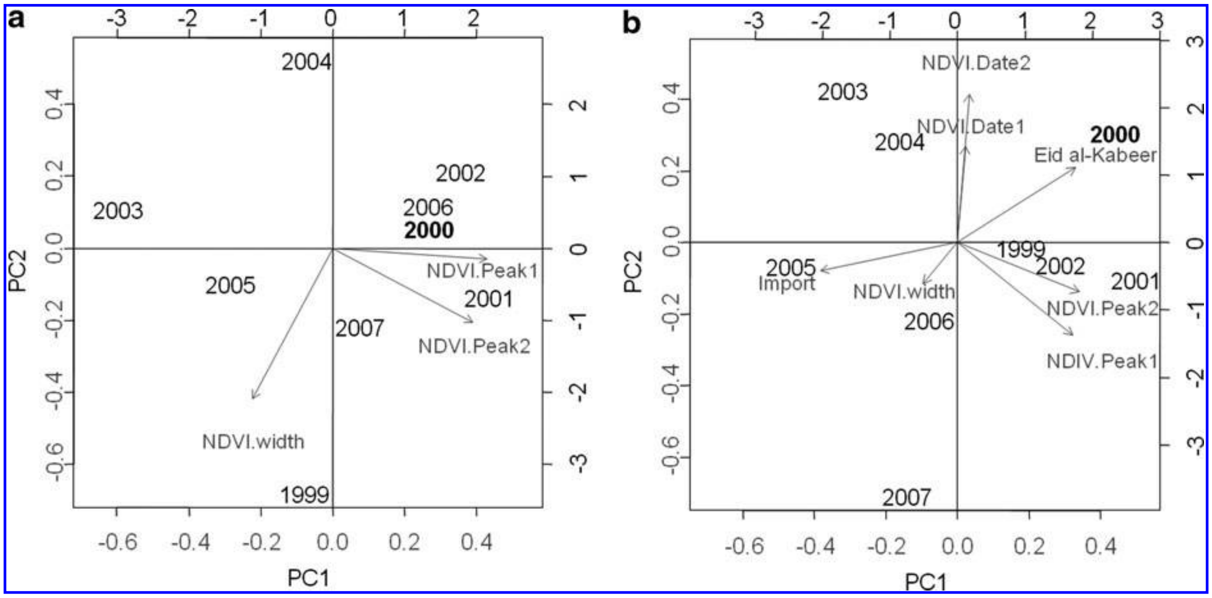

FIG. 3. Composition of the PC1 and PC2 and projection of the different years (1999–2007) (in black) and the factors (in gray) on the first PC analysis plan. PC, principal component. **(a)** Results of the principal component analysis with environmental variables only. **(b)** Results of the PCA with all environmental and socioeconomic variables.

Discussion

The drivers of an emerging disease that occurs for the first time in a former disease-free area are difficult to identify. When, in addition, the disease emerge and then apparently disappear for another 10 years, limited epidemiological data are available, as was the case for the unique RVF outbreak in Yemen in 2000–2001. However, given the huge and dramatic social and economic impact of RVF (Ahmad 2000, CDC 2000a, 2000b, Al Qadasi 2002), data from this unique outbreak, in addition to the results of studies conducted in RVF endemic regions, should be exploited in an attempt to identify pertinent risk indicators to target surveillance measures.

Although none of the usually known indicators for RVF emergence in East of Africa was clearly related to this event in Yemen, the present study aimed to further explore the association of different possible drivers in the year 2000, compared with other recent years (1999–2007). For RVF to be transmitted, three components must be present: the pathogen (RVFV), the vectors (mosquitoes), and the hosts (cattle and/or small ruminants). The variables that we used to characterize each year were thus chosen for the following reasons:

- The number of animals imported was used as a proxy for the risk of introduction of the virus from countries in the Horn of Africa as it was demonstrated that the virus kept on circulating even during the interepizootic period (1999–2006) (Rostal et al. 2010).
- Environmental variables (NDVI characteristics) were chosen because they are known to drive the increase of vector abundance on the Horn of Africa.
- The Eid al-Kabeer celebration calendar was included as an indicator of the date of high concentrations of hosts, favoring both RVFV introduction and amplification when vector densities are sufficiently high.

When bioclimatic factors alone are taken into account, this descriptive approach reveals that the year 2000 was not significantly different from other years in the studied period (1999–2007).

However, when other socioeconomic factors are included, 2000 appears atypical regarding (i) the characteristics of NDVI peaks (maximum values for both rainy seasons), (ii) the starting date of the Eid al-Kabeer festival (coinciding with the start of the March rains), and (iii) the number of imported animals (relatively low).

TABLE 3. RESULTS OF THE PRINCIPAL COMPONENT ANALYSIS: ROTATED FACTOR MATRIX AND PROPORTION OF VARIANCE—SEVEN ENVIRONMENTAL AND SOCIOECONOMIC VARIABLES, YEMEN, 1999–2007

Variables	*Notation*	*PC1*	*PC2*	*PC3*	*PC4*	*PC5*	*PC6*
Date of the NDVI peak, first rainy season	NDVI.Date_Peak1	0.03	0.43	0.55	−0.13	0.70	−0.02
Date of the NDVI peak, second rainy season	NDVI.Date_Peak2	0.05	0.66	−0.23	0.25	−0.25	−0.01
Maximum of NDVI, first rainy season	NDVI.Peak1	0.43	−0.41	0.27	−0.13	−0.06	0.48
Maximum of NDVI, second rainy season	NDVI.Peak2	0.49	−0.22	−0.10	0.68	0.31	−0.39
Width of the second rainy season peak	NDVI.Width	−0.14	−0.18	−0.66	−0.33	0.54	−0.04
Number of imported animals	Import	−0.55	−0.13	0.01	0.58	0.21	0.55
Starting date of Eid al-Kabeer	Eid	0.47	0.33	−0.35	−0.01	0.12	0.56
Proportion of variance		0.34	0.27	0.25	0.09	0.03	0.02
Cumulative proportion of variance		0.34	0.61	0.86	0.95	0.98	1.00

These results are consistent with the hypothesis that the virus was already present in Yemen in 2000, as has been suggested by Madani et al. (2003) and Davies (2000), and that the social and environmental conditions were probably favorable for the amplification of the RVF cycle. The concentration of livestock for the Eid al-Kabeer celebrations, which began that year relatively late (March), coincided with the beginning of the first rainy season, which saw important precipitation. This suggests the following possible scenario: in 2000, the coincidence of a social event driving high concentration of livestock and bioclimatic conditions favoring high vector population densities allowed the amplification of the transmission cycle during the first rainy season, followed by a second amplification in summer from virus persisting at low levels in residual *Culex* populations between the two rain seasons. The Yemeni and Saudi Arabian outbreaks occurred in similar ecological and climatic contexts, suggesting that the same vectors were involved, namely *Aedes vexans* and *Culex tritaeniorhynchus* (Jupp et al. 2002, Miller et al. 2002), and that the emergence processes were similar. As the second rainy season also featured high levels of rainfall and thus high *Aedes* and *Culex* mosquito vector densities, the RVF transmission cycle may have been reinitiated with the onset of the autumn rains at high levels of transmission, leading to the declared outbreaks in September. This scenario remains hypothetic as there is no virological or serological data available to support it. Yet, our hypothesis could explain the results of serological surveillance since 2001. The surveillance in Yemen, where animals are not vaccinated, was greatly improved after the RVF outbreak in 2001, as well as the screening of imported animals and the follow-up of RVFV activity at a regional level. The results of the surveillance performed by the Yemeni veterinary services suggest that the virus did not persist or circulated only at a very low level after 2001 (Al Qadasi 2009, Abdo-Salem et al. 2010). These results are in concordance with the hypothesis of a necessary conjunction of environmental and socioeconomic conditions for RVFV amplification. Indeed, such hypothesis could explain that there was no other outbreak in Yemen after 2001, even in the 2006–2007 period, when a severe outbreak occurred in East Africa during the Eid al-Kabeer festival (Jost et al. 2010). In Yemen, bioclimatic conditions seem favorable to vector populations (high NDVI peaks in September 2006 and April 2007; see Table 1 and Fig. 3a) (Anyamba et al. 2006a). Nevertheless, despite of these "at-risk" conditions, there was no serological evidence of RVFV circulation in Yemen during this period (Al Qadasi 2009), possibly because the Eid al-Kabeer festival occurred in January and not in the periods favorable to mosquito development.

Whether the RVFV was present in Yemen prior to 2000 or was introduced that year remains unconfirmed. The main rainy season in Somalia, which occurs between March and May, may be considered to be the risk period for virus transmission in this country. The importation of animals during this period in 2000 consequently may have facilitated the introduction of infected animals into Yemen. Even if fewer animals were imported into Yemen in 2000 compared with other years, this number remains sufficiently high (>200,000) to consider the risk of virus introduction as having been high in 2000. Moreover, the number of imported animals may be underestimated, as smuggling livestock along the borders is common. To conclude, if the virus was introduced into Yemen in 2000, then our results suggest that the dates of importation appear to be more important than the quantity of animals imported.

According to the results of this descriptive approach (Table 1), 1999 resembled 2000 in terms of its climatic profile and relatively late Eid al-Kabeer celebrations. These conditions thus should have resulted in an introduction and amplification of the RVFV in 1999 as well. It, therefore, seems possible that the disease detected in 2000 resulted from two consecutive years favorable to the amplification of the virus.

Our results should be interpreted cautiously because of the limited number of years considered and the lack of information about the mosquito populations present in the study area. Further studies are required to precise the successive links between rainfall, vegetation indices, and mosquito dynamics.

However, the conjunction of two rainy seasons presenting above-normal precipitations and a starting date for the Eid al-Kabeer festival coinciding with the start of the spring rainy season seem to have contributed to the emergence of RVF in Yemen in 2000. These factors should be taken into account for the implementation of early-warning systems in the country. At present, it is unknown whether RVFV survived in Yemen after the 2000 outbreak. Because of subsequent very dry and hot conditions, it is likely that it did not. However, RVF is endemic in the Horn of Africa and the risk of reintroduction into the Arabian Peninsula remains.

In conclusion, our results show that environmental conditions were not the only determinants of the emergence of RVF in Yemen, thereby highlighting the importance of including social variables along with environmental ones in the assessment of RVF risk.

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Disclosure Statement

No competing financial interests exist.

References

Abdo-Salem, S, Gerbier, G, Bonnet, P, Al-Qadasi, M, et al. Descriptive and spatial epidemiology of Rift valley fever outbreak in Yemen 2000-2001. Ann N Y Acad Sci 2006; 1081:240–242.

Abdo-Salem, S, Waret-Szkuta, A, Roger, F, Olive, MM, et al. Risk assessment of the introduction of Rift Valley fever from the Horn of Africa to Yemen via legal trade of small ruminants. Tropical Animal Health and Production 2010; Available at http://dx.doi.org/10.1007/s11250-010-9719-7.

Ahmad, K. More deaths from Rift Valley fever in Saudi Arabia and Yemen. Lancet 2000; 356:1422.

Alary, V. Etude du commerce régional du bétail et des produits animaux en Afrique de l'Ouest (zone ECOWAS) et Afrique de l'Est (zone IGAD). Montpellier, France: CIRAD, 2006.

Al Qadasi, M. Rift valley Fever outbreak in Yemen Sep2000/ March 2001 and surveillance follow up. Presented at the Rift Valley Fever Workshop: An Integrated Approach to Controlling Rift Valley Fever (RVF) in Africa and the Middle East, Cairo, Egypt, 2009.

Al Qadasi, M. Rift Valley fever outbreak in Yemen, September 2000 to February 2001. Presented at the World Veterinary Congress, Tunis, 2002.

Anyamba, A, Chretien, JP, Formenty, PBH, Small, J, et al. Rift Valley fever potential, Arabian Peninsula. Emerg Infect Dis 2006a; 12:518–520.

Anyamba, A, Chretien, JP, Small, J, Tucker, CJ, et al. Developing global climate anomalies suggest potential disease risks for 2006-2007. Int J Health Geogr 2006b; 5:60.

Anyamba, A, Chretien, JP, Small, J, Tucker, CJ, et al. Forecasting the temporal and spatial distribution of a rift valley fever outbreak in east Africa: 2006-2007. Am J Trop Med Hyg 2007; 77:282–283.

Anyamba, A, Chretien, JP, Small, J, Tucker, CJ, et al. Prediction of a Rift Valley fever outbreak. Proc Natl Acad Sci U S A 2009; 106:955–959.

CDC. Outbreak of Rift Valley fever, Yemen, August-October 2000. Wkly Epidemiol Rec 2000a; 75:392–395.

CDC. Update: Outbreak of Rift Valley fever- Saudi Arabia-August-October, 2000. Morb Mortal Wkly Rep 2000b; 49:905–908.

Chevalier, V, Martin, V, De la Rocque, S, Roger, F. Combating and predicting Rift Valley fever outbreaks: a scientific and geopolitical challenge for the future. In: Scheld, WM, Hammer, SM, Hughes, JM, eds. *Emerging Infections* 8. Washington: ASM Press, 2008:189–212.

Davenport, ML, Nicholson, SE. On the relation between rainfall and the normalized difference vegetation index for diverse vegetation types in East-Africa. Int J Remote Sensing 1993; 14:2369–2389.

Davies, FG. Risk of a rift valley fever epidemic at the Haj in Mecca, Saudi Arabia. Revue Scientifique et Technique de l'Office International des Epizooties 2006; 25:137–147.

Davies, FG. *Rift Valley Fever in Yemen*. Rome: Food and Agriculture Organization, 2000.

Fleming, DE, Hammadi, N, Alqadasi, MSA, Saed, K. *Livestock Movement and Trade Study for the Yemen Agricultural Support*. Burlington: ARD, Inc., 2008.

Gerdes, GH. Rift Valley fever. Revue Scientifique et Technique de l'Office International des Epizooties 2004; 23:613–623.

Haas, EM, Bartholome, E, Combal, B. Time series analysis of optical remote sensing data for the mapping of temporary surface water bodies in sub-Saharan western Africa. J Hydrology 2009; 370:52–63.

Jost, CC, Nzietchueng, S, Kihu, S, Bett, B, et al. Epidemiological assessment of the Rift Valley fever outbreak in Kenya and Tanzania in 2006 and 2007. Am J Trop Med Hyg 2010; 83:65–72.

Jupp, PG, Kemp, A, Grobbelaar, A, Leman, P, et al. The 2000 epidemic of Rift Valley fever in Saudi Arabia: mosquito vector studies. Med Vet Entomol 2002; 16:245–252.

Linthicum, KJ, Anyamba, A, Tucker, CJ, Kelley, PW, et al. Climate and satellite indicators to forecast Rift Valley fever epidemics in Kenya. Science 1999; 285:397–400.

Linthicum, KJ, Davies, FG, Kairo, A, Bailey, CL. Rift Valley fever virus (family *Bunyaviridae*, genus *Phlebovirus*). Isolations from *Diptera* collected during an inter-epizootic period in Kenya. J Hyg 1985; 95:197–209.

Madani, TA, Al-Mazrou, YY, Al-Jeffri, MH, Mishkhas, AA, et al. Rift Valley fever epidemic in Saudi Arabia: epidemiological, clinical, and laboratory characteristics. Clin Infect Dis 2003; 37:1084–1092.

Miller, BR, Godsey, MS, Crabtree, MB, Savage, HM, et al. Isolation and genetic characterization of Rift Valley fever from *Aedes vexans arabiensis*, Kingdom of Saudi Arabia. Emerg Infect Dis 2002; 8:1492–1494.

Nicholson, SE, Farrar, TJ. The influence of soil type on the relationships between NDVI, rainfall, and soil-moisture in semiarid Botswana .1. NDVI response to rainfall. Remote Sensing Environ 1994; 50:107–120.

Noaman, AA. Ecohydrological-erosion model for semi-arid mountain catchment using GIS techniques: A case study-wadi surdad catchment, Republic of Yemen. The Arabian Journal for science and engineering 2005; 30:99–109.

O'Malley, CM. 1990. Aedes Vexans (Meigen, 1830): an old foe. In: Proceedings of the 77th Annual Meeting of the New Jersey Mosquito Control Association (NJMCA), 13–15 June, CherryHill, New Jersey. NJMCA, New Jersey, 90–95.

Rostal, M, Evans, A, Sang, R, Gikundi, S, et al. Identification of potential vectors of and detection of antibodies against Rift Valley fever virus in livestock during interepizootic periods. AmJ Vet Res 2010; 71:524–528.

Shoemaker, T, Boulianne, C, Vincent, MJ, Pezzanite, L, et al. Genetic analysis of viruses associated with emergence of Rift Valley fever in Saudi Arabia and Yemen, 2000-2001. Emerg Infect Dis 2002; 8:1415–1420.

Soti, V, Tran, A, Bailly, J-S, Puech, P, et al. Assessing optical Earth observation systems for mapping and monitoring temporary ponds in arid areas. Int J Applied Earth Observ Geoinf 2009; 11:344–351.

Swanepoel, R, Coetzer, JAW. Rift Valley fever. In: Coetzer, J, Tustin, RC, eds. *Infectious Diseases of Livestock.* Cape Town: Oxford University Press, 2004:1037–1070.

Swanepoel, R, Coetzer, JAW. Rift Valley Fever. In: Tustin, JCAR, ed. *Infectious Diseases of Livestock.* Oxford University Press, 2004:1037–1070.

Tihama Development Authority. Wadi development for agriculture in Yemen Arab Republic. In: Proceedings of the Subregional Expert Consultation on Wadi Development for Agriculture in the Natural Yemen. Hodeidah, Yemen, 1987.

WHO. Outbreak of Rift Valley Fever, Yemen. Wkly Epidemiol Rec 2000; 75:385–396.

WHO. Rift Valley fever Factsheet. World Health Organization 2007. Available at www.who.int/mediacentre/factsheets/fs207/en/.

Woods, CW, Karpati, AM, Grein, T, McCarthy, N, et al. An outbreak of Rift Valley fever in northeastern Kenya, 1997-98. Emerg Infect Dis 2002; 8:138–144.

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Chapter 6: Risk assessment of the introduction of Rift Valley Fever from the Horn of Africa to Yemen via legal trade of small ruminants

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ORIGINAL RESEARCH

Risk assessment of the introduction of Rift Valley fever from the Horn of Africa to Yemen via legal trade of small ruminants

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Abstract Rift Valley fever (RVF) is a mosquito-borne viral zoonosis of increasing global importance. Occurring since 1930 across Africa, it was detected for the first time in Saudi Arabia and Yemen in September 2000, leading to human deaths and major losses in livestock populations. Assuming the virus has not survived in Yemen or has been circulating at a low level, authors qualitatively assessed the likelihood of "re-introduction" of RVF into Yemen through the legal importation of small ruminants from the Horn of Africa. The overall probability of introduction was assessed very low to medium, increasing during festival periods and higher when considering a direct transmission exposure as compared to a vectorial transmission exposure. The uncertainty was considered to be medium underlining important gaps in information that need to be fulfilled in the region. Options to reduce the risk are proposed and discussed, including possible improvements of the current Yemeni quarantine system.

Keywords Rift Valley fever · Yemen · Risk assessment · Horn of Africa · Trade

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Introduction

Rift Valley fever (RVF) is a mosquito-borne viral zoonosis of increasing global importance. The RVF virus (RVFV) belongs to the genus *Phlebovirus* (family *Bunyaviridae*) and may be transmitted by more than 30 mosquito species (EFSA 2005). However, *Aedes* and *Culex* genera are considered to be the main vectors.

Sheep, goats and cattle are the main species affected. The main clinical signs are massive abortions in pregnant females and mortalities in young animals. However, considerable RVFV activity may occur in ruminants without any obvious clinical signs.

Vector-borne transmission is the main transmission mechanism of RVFV from ruminants to ruminants during inter-epizootic periods. Direct transmission is probably the main route of infection for animals and humans during epizootic periods, which become infected from contact with blood, abortion products or any other infected biological material during the viraemia (Davies and Martin 2006).

RVF appeared for the first time in 1930 in Kenya (Daubney et al. 1931) near Lake Neivasha located in the Great Rift Valley. Since then RVF has been encountered in an enzootic or epizootic form in most African countries and in Madagascar (Gerdes 2004). The virus has spread as far north as Egypt, and its recent confirmation in Mayotte (Indian Ocean island located in the Comoros Archipelago) reminded its high potential of geographic extension. In both cases, this extension was suspected to be linked to ruminant trade, coming from Sudan to Egypt and from Eastern Africa to the Comoros Archipelago (Abd El-Rahim et al. 1999; InVS 2007).

RVFV was detected for the first time outside the African continent in September 2000, leading to human deaths and

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major losses in livestock populations in Saudi Arabia and Yemen (Ahmad 2000). Six viral strains were isolated from *Aedes* mosquitoes, phylogenetically close to the strain isolated in Kenya (1997–1998). As for Egypt and Mayotte, the virus was thought to have been introduced by ruminants into the Arabic Peninsula from Kenya that had experienced a severe outbreak in 1998 (Shoemaker et al. 2002; Madani et al. 2003).

Due to its unique geographical position with short distances to ports on the coast of the Horn of Africa, Yemen is a crossroad for animal trading between Africa and the Arabian Peninsula. More than 1,000,000 animals enter the country each year, this without considering illegal trade, from the Horn of Africa with the importation of cattle and small ruminants estimated to account for 25% and 40% respectively of the total meat consumed in Yemen. In the last 10 years, the numbers of imported livestock to Yemen increased by 643% where the livestock sector contributes 30–33% of the agricultural output and accounts for 20% of the national income (ARD 2006). It is apparent that the Yemeni livestock owners have become very dependent on imported livestock to maintain the size of their herds. Thus, a ban on the importation following an epizootic disease outbreak as was encountered in 2000 with RVF would have dramatical socio-economic consequences on both sides (Holleman 2002; ARD 2006; Soumare et al. 2007).

Whether RVFV was present or not in Yemen before 2000, and persisted or not after the outbreak, remains unknown. However, the results of serological monitoring performed between 2004 and 2008 demonstrated an immunoglobulin M (IgM) prevalence rate <0.1% (CVL Sana'a, Yemen) suggesting that the virus did not keep on circulating in Yemen after the 2000 outbreak or has been circulating at a very low level without being detected (Tesh et al. 2002).

In this study, we assumed that the virus disappeared after the 2000 outbreak and could be re-introduced via ruminant trade from the Horn of Africa. We assessed this risk of introduction, taking into account legal trade of small ruminants from this region, namely from Kenya, Somalia, Djibouti and Ethiopia. The probability of viable RVFV entering Yemen from the Horn of Africa along with the probability of exposure of livestock within Yemen to viable RVFV was assessed qualitatively per month on a yearly period.

Materials and methods

The pathway resulting in the possible release of viable RVFV into Yemen from the Horn of Africa is presented Fig. 1. Given the situation that RVFV has entered Yemen, the exposure assessment scenarios will follow the different possible routes by which Yemeni livestock could be exposed to the virus. Available information needed to assess each step of the different pathways is presented hereafter.

Prevalence and incidence of RVF on small ruminants in the Horn of Africa

Few studies have been conducted to our knowledge to estimate the prevalence and incidence rates of RVF on small ruminants, either during inter-epizootic or epizootic

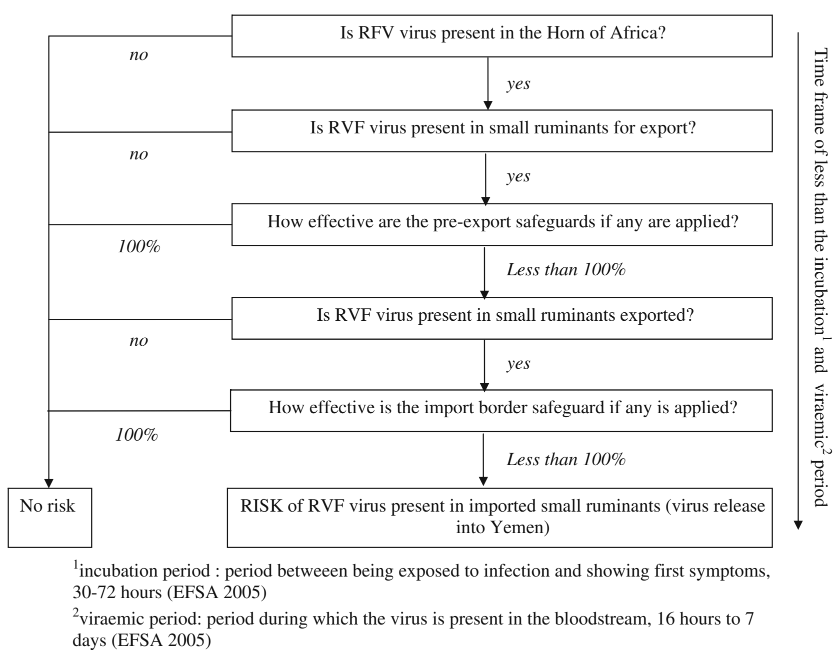

Fig. 1 Import risk release pathway for Rift Valley fever virus into Yemen via small ruminants (adapted from EFSA (2005))

periods. Results found for West Africa are summarized in Table 1.

In East Africa where RVF is endemic, RVF epidemics occur at 5 to 15 years cycles (EFSA 2005; Kasari et al. 2008). Not much data is available in the Horn of Africa (Clements et al. 2007) to determine the seroprevalence in these countries, especially during inter-epizootic periods.

In Somalia, investigations both in Somaliland and Puntland (north west and north east of the country, respectively) revealed a scattered distribution of RVF infection with the highest antibody seroprevalence mostly in the Nugal Valley (south of Puntland) where RVFV activity seems to be on increase. Screening in Somaliland in 2001 and Puntland in 2003, which targeted mainly sheep and goats, revealed no signs compatible with the disease but an overall IgG seroprevalence of 2±0.02% (90/4,570) and 5±0.3% (206/4,050), respectively. The spatial distribution showed clusters of high seroprevalence located mostly in the Nugal Valley confirmed by a follow-up survey in 2004 suggesting a maintenance and increase of RVFV activity in the valley. In addition, conditions favourable to the breeding and survival of the vector population and the high density of livestock make the Nugal Valley an area of high risk for an RVF outbreak according to the authors (Soumare et al. 2007).

By the end of 2006, the disease has re-emerged in Kenya, then in Tanzania and Somalia. Another large epidemic hit the Sudan in 2007, in the River Nile Valley around Khartoum where outbreaks were recorded up to the bordering province Kassala (CDC 2007; WHO 2007a, b). However, no cases have been reported in Ethiopia where "the Ethiopian government […] has been assessing the borders and has collected epidemiologically important numbers of samples and produced diagnoses using internationally recognised diagnostic tools" having "no indication confirming the presence of RVF in the country" (Gebreegziabher 2008).

Following a change in the environmental conditions that resulted in major outbreak of RVF in north-eastern Kenya and suspected but unconfirmed foci of the disease in southern Somalia, a targeted survey was commissioned by FAO Somalia (under the Norwegian Government funded FAO project "Emergency Livestock Disease Surveillance and Vaccination/Treatment in Support of Pastoralist Livelihood in Flood-Affected Areas of Southern Somalia"). The targeted RVF surveillance showed clusters of high seroprevalence located mostly in the southern Somalia districts namely: Jilib, Jamaame, Bedhaadhe, Afmadow, Buaale, Baardheere, Saakow, Luuq, Garbajarey and B/hawo, respectively. In Jamame District of Lower Juba Region, 60 serum samples were collected in a village where RVF clinical signs were present in a flock of sheep, and tested for IgM antibodies; 40% (24/60) were IgM positive, indicating recent virus circulation. At the same time in central Somalia, a targeted sampling for RVF showed clusters of lower seroprevalence located mostly in six districts: Mahaday, Balcad, Jowher, Jalalaqsi, Beletweyne and Buloburto.

Serological tests to detect RVFV antibodies include the virus neutralisation test (VNT), and enzyme-linked immunosorbent assays. VNT is the gold standard, the cross reactions with other Phleboviruses being limited (Tesh et al. 2002).

Taking into account the data presented above, in the enzootic areas, approximately 0.5–5% of the animals may be infected with RVFV, the proportion increasing during epidemics that often correspond in East Africa to periods of widespread, frequent, heavy and persistent rainfall as shown by historical information (EFSA 2005).

Therefore, two climatic scenarios can be distinguished for RVF viral circulation in the Horn of Africa and more particularly in the areas exporting small ruminants: the dry and the rainy seasons. Indeed, during the dry season (interepidemic period), and because of a low mosquito density, the viral circulation among susceptible species is likely to be much lower than during the two rainy seasons: January to March and July to September (Saeed 2008)

Small ruminant legal exportation from the Horn of Africa to Yemen: description of flows

Most livestock imported into Yemen comes from Kenya and Ethiopia through Somalia. The flow of small ruminants that arrives in Yemen was estimated to be 1,597,649 in 2007 as shown in Table 2 (ARD 2006; Alary 2006), this without including the estimated 1,000,000 sheep shipped through informal market channel (economic activity that is neither taxed nor monitored by a government and is not included in that government's Gross National Product; Alary 2006). The majority of imported livestock are 2 to 5 years old rams (the proportion reaching 95% in the high peak period), with a few females reported (ARD 2006).

Livestock passes through the local markets in Somalia and end up concentrating the ports of Berbera and Bossasso

Table 1 Prevalence rates reported for Senegal on small ruminants

Localisation	Period	Prevalence rates	References
Senegal river basin	1987 1994–1995	16–80% (IgM) 12.5% (IgM)	Ksiazek et al. (1989); Nabeth et al. (2001); Thonnon et al. (1999)
Ferlo area (North Senegal)	1991–1993	3% (IgG)	Chevalier et al. (2005)

Table 2 Number of small ruminants imported from the Horn of Africa to Yemen from 2003 to 2007 (source: Yemen Quarantine Authority, personal communication)

Years	Ports in Yemen	Ports in Horn of Africa	
	Al-Mukall and Mukkha	Djibouti	Berbera and Bossasso
2004	1,190,078		2,024,836
2005	1,170,057		1,021
2006	1,335,130	1,617,832	2,045,566
2007	1,265,062	1,272,779	1,597,649

on the Red Sea, the main informal circuit being between Ethiopia and Somaliland, the alternative being the way through Djibouti. Then, around 60% of the total small ruminants exported are loaded onto ships bound for the ports of Mukkha, 15% to Aden and 25% to Al-Mukall, the main quarantine stations in Yemen, as shown on Fig. 2.

Upon leaving the facility at Mukha, 30% of the small ruminants travel to Sana'a. The next two destinations, which receive approximately 25% of small ruminants, are Taiz and Hodeidah. A small amount travels to Ibb (ARD 2006). At Al-Mukall, the majority of sheep/goats go to the markets of Shahr and Al-Mukall (30% each). Twenty-five

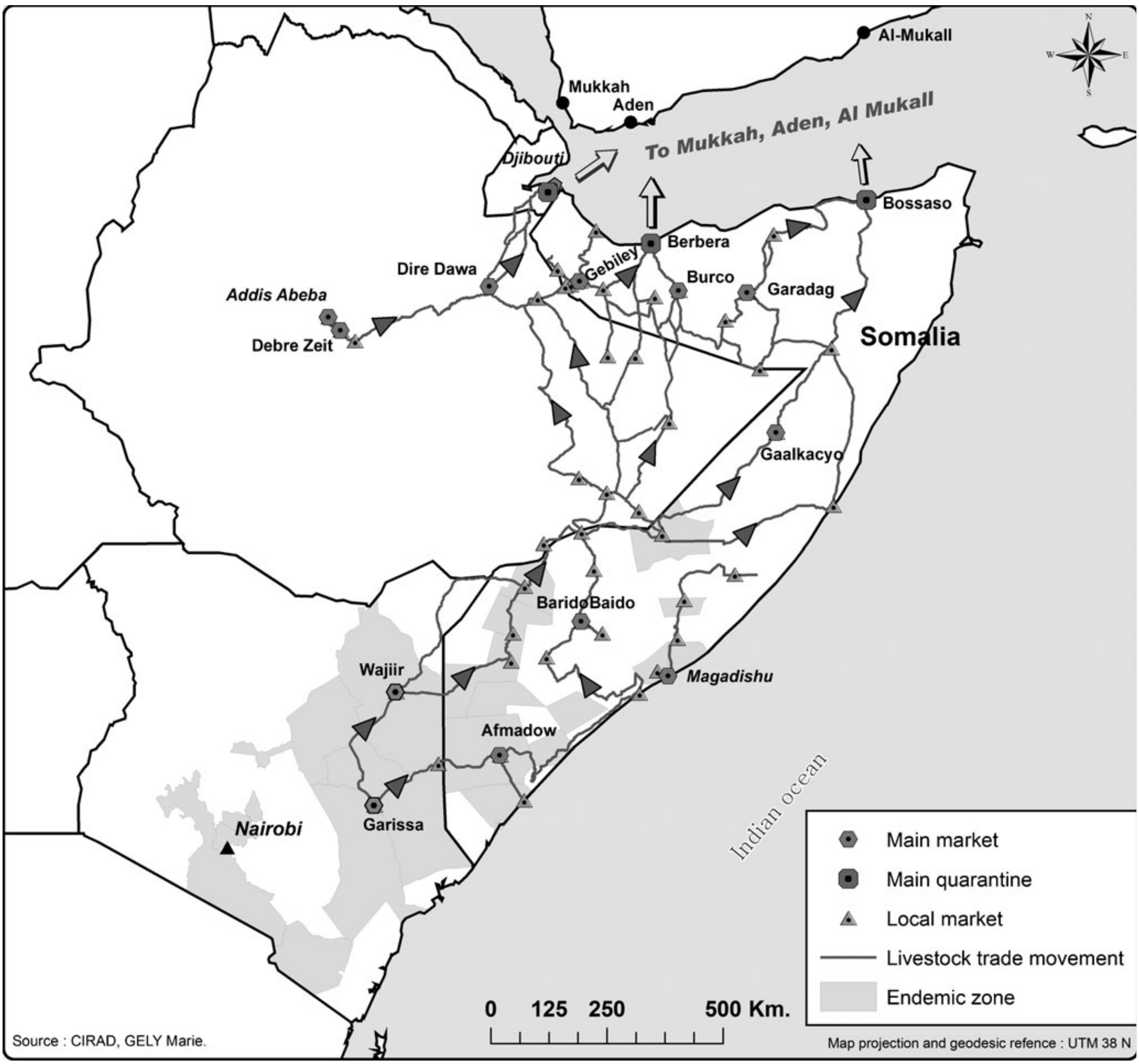

Fig. 2 Movements of live animals from Somalia, Kenya and Ethiopia to Yemen through Bossasso, Berbera and Djibouti seaport. The 'endemic zone' represents the districts where RVF outbreaks were reported in 1997/1998 and 2006/2007 (WHO 2007c)

percent go to the Hadrarmawt Valley. The livestock imported into Aden is taken to local markets and sold for local slaughter (ARD 2006; Fig. 3). The Yemen market is also a transhipment point for animals to other Gulf States, particularly Saudi Arabia (Alary 2006).

During the festival periods, there is a peak in the number of animals exported corresponding to a high demand in Yemen as each religious Muslim has traditionally to slaughter one ram during Eid al-Adha, for example; whereas during the non-festival periods, there is a lower number of animals exported and that encompasses more females compared to festival periods. Therefore, Muslim festival periods should be distinguished from non-festival periods for the release assessment.

Mode of transport and transport duration from the Horn of Africa to Yemen

All live animals arriving to Yemen arrive by boats called Dawh and small ships with a capacity for 200 to 2,000 heads. None are reported to be exported alive by plane (Aklilu 2002). Transit times are usually of 1 to 2 days from the ports of Djibouti or Somalia to Yemen (Wilson et al. 2004).

Although it was not possible to determine precisely the time of transit between any origin in Kenya, Somalia or Ethiopia to the ports of exportation, it is likely to be less than 2 days by truck or train via the main routes of transportation (Dirie and Wais 2005). Considering the viraemia duration (ranging from 16 h in lambs to 7 days in adult sheep and goats (EFSA 2005)), animals leaving their origin country being viraemic may enter viraemic in Yemen.

Mitigation measures: pre- or post-export control measures

Ethiopia has collecting points that play the role of quarantine, where animals are gathered, fed, treated and vaccinated. Animals are kept there around 20 to 30 days before being exported by rail or trucks to Djibouti quarantine station. From Djibouti, they will be directly shipped on boat to Yemen, without further examination, where Yemeni traders acknowledge the sanitary certificate delivered by Ethiopian veterinary services in the collecting

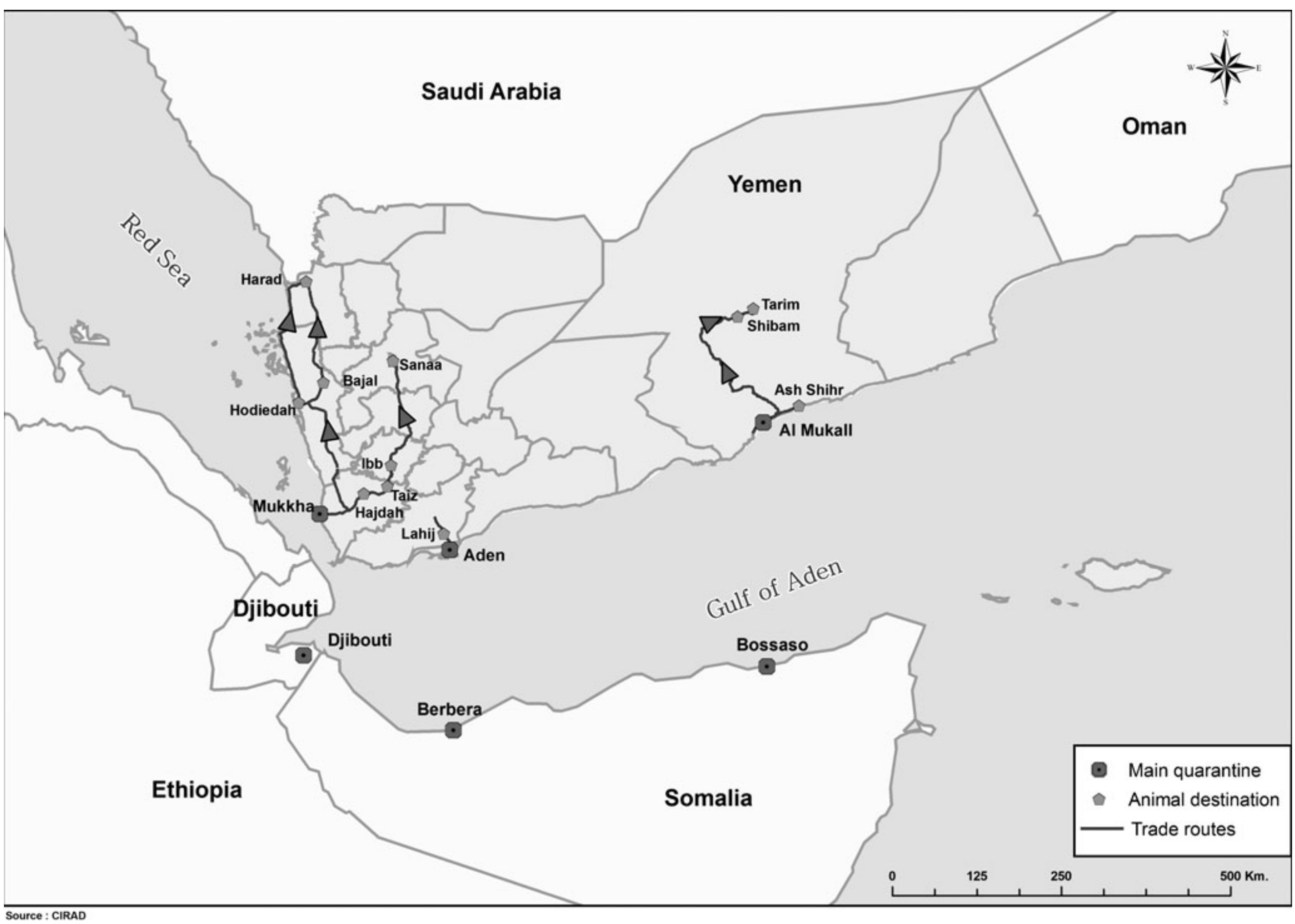

Fig. 3 Movements of live animals in Yemen after shipment from the Horn of Africa

point. No data could be found about existing pre-export measures in Somalia.

Once in Yemen and upon being unloaded from the ships, the animals either walk or are transported to the quarantine, where they receive a visual inspection by a veterinarian or a veterinarian assistant. There is no or little isolation of animals, newly arrived animals readily coming with livestock that are soon to be released. Blood samples are only intermittently drawn for disease confirmation upon clinical suspicion and no vaccinations are given. The livestock are observed for anorexia and ataxia for 2 to 10 days before being released into the country, 2 days corresponding to high volume periods of animals coming in, for example during Muslim festival periods (ARD 2006).

Number of susceptible animals in Yemen (that could come into contact)

The sheep, goats, cattle and camels in Yemen are mainly located in the western part of the country, along the coast and irrigated valley. Total numbers according to FAO are reported in Table 3.

Mosquito density (in relation with the vectorial transmission for the exposure assessment)

Culex and *Aedes* mosquitoes are considered the main vectors of RVF. Even if their biology is quite different—*Culex* populations need permanent water to develop whereas *Aedes* populations need succession of dry and wet periods, their density is strongly linked to the water, thus partially to the rainfall pattern. In Yemen, two flooding periods can be distinguished, respectively, in March–May and in July–September (Alabsi 2006). Permanent water due to irrigated systems as well as temporary rivers flooded by water coming from the mountains during the rainy seasons (Wadi) may be encountered. Although no entomological studies have been performed and due to this particular water network in Yemen, both *Culex* and *Aedes* species may play a role in the RVF epidemiological cycle (Chevalier et al. 2008): *Culex* mosquitoes could transmit the virus whatever the period they are exposed, whereas *Aedes* would be involved only during rainy season.

Pathways and data analysis, table of qualitative terms used and definition of uncertainty levels

After having identified the release pathway by which RVF could enter Yemen due to the introduction of small ruminants (Fig. 1), the available information presented above led us to distinguish and qualitatively assess four scenarios (Table 4) impacting mainly on the first and fourth step of the release pathway ('virus present in the Horn of Africa' and 'virus present in small ruminants exported', respectively):

- Scenario 1: rainy season in the Horn corresponding to the time of the occurrence of festivals
- Scenario 2: rainy season in the Horn but not corresponding to the time of the occurrence of festivals
- Scenario 3: dry season in the Horn corresponding to the time of the occurrence of festivals
- Scenario 4: dry season in the Horn, not corresponding to the time of occurrence of festivals

Regarding to the exposure, two possibilities for transmission were considered:

- Infection of competent vectors and subsequent transmission from these to indigenous or exotic breeds of livestock
- Exposure of livestock to infective materials of infected animals (product of abortion) and subsequent infection

In each case, transmission could occur in Yemen either during the rainy season (scenario A) or during the dry season in the country (scenario B; Table 5).

The terms used to describe the probability of undesired outcomes in the different scenarios were defined by the authors as:

- Very low (VL): very rare but cannot be excluded
- Low (L): rare but does occur
- Medium (M): occurs regularly
- High (H): occurs very often

In order to combine the likelihood of the scenarios by multiplying their qualitative values, the matrix presented in Table 6 adapted from Zepeda (1997) was used.

Three levels of uncertainty were considered and agreed upon (Table 7): low (L), medium (M) and high (H).

Table 3 Livestock and species number in Yemen from 2000 to 2006 (source: FAO (2010))

	2000	2001	2002	2003	2004	2005	2006
Sheep	6,193,000	6,483,000	6,548,000	7,819,000	7,899,243	7,980,213	8,197,024
Goats	6,918,000	7,246,000	7,318,000	7,707,000	7,785,212	7,864,122	8,041,955
Cattle	1,283,000	1,342,000	1,355,000	1,418,000	1,433,213	1,447,243	1,463,700
Camels	253,000	264,000	267,000	350,000	353,211	357,011	359,000

Table 4 Summary of the four scenarios for the introduction of RVFV into Yemen from the Horn of Africa via small ruminant's legal trade

	Rainy season in the Horn	Festival period	Risk
Scenario 1	Yes	Yes	M
Scenario 2	Yes	No	L
Scenario 3	No	Yes	L
Scenario 4	No	No	VL

VL very low, *L* low, *M* medium, *H* high

Table 6 Combination matrix of the likelihood of two events using qualitative values (adapted from Zepeda (1997))

	×	Likelihood of event 2			
		VL	L	M	H
Likelihood of event 1	VL	VL	L	L	M
	L	L	L	M	M
	M	L	M	M	H
	H	M	M	H	H

Results

Release assessment

The current transport duration for livestock shipments from the Horn of Africa to Yemen is shorter than the incubation plus viraemic periods in indigenous sheep and goats. Therefore, the import of sheep and goats as currently practiced from the Horn with hardly any pre- or post-mitigation measures present a risk of landing RVF viraemic animals following the release pathway shown on Fig. 1.

Results of the assessment of the four scenarios distinguished for the release of RVFV in Yemen are summarized in Table 5. They take into account the influence of rain occurrence in the Horn on the probability of epidemics linked to the mosquito density and the impact of the festival periods (periods that vary according to the year) on the number of small ruminants exported.

Uncertainty lays in the fact that indigenous "fat tailed" sheep are relatively refractory to infection and that, if infected, are likely to respond with viraemia of only short duration (Davies and Nunn 1998). It is increased by the fact that duration time for transport may vary. Moreover, an animal or animals not infected with nor incubating RVFV before leaving the Horn of Africa would pose no hazard unless infected during shipment. Theoretically, this could occur if an animal or animals were bitten by an infected vector or in contact with a viraemic animal during shipment but was not considered here. Thus, uncertainty was considered as high.

Table 5 Summary of the findings for the two scenarios considered for the exposure assessment following the release of RVFV in Yemen

	Vector-borne	Direct
Scenario A: rainy season in Yemen	M	M
Scenario B: dry season in Yemen	VL	M

VL very low, *L* low, *M* medium, *H* high

Exposure assessment

Table 5 shows the result for each of the two routes of exposure (vector-borne and direct transmission) and the two scenarios A and B considered (occurrence of the rainy or dry season in Yemen, respectively, at the time of exposure).

Uncertainty can be here considered as low according to the numerous references that refer or demonstrate the underlying assumptions of these two scenarios.

Overall measure of the risk

In order to combine the different release and exposure scenarios (Tables 4 and 5) the year was divided into four different periods (Fig. 4):

– From January to March (scenario 1 and 2 combined with scenario B): first rainy season in the Horn, dry season in Yemen. The overall risk is M when considering direct transmission as the exposure route in Yemen and L when considering the vector-borne transmission route at either of the period considered (festival or not).
– From March to May (scenario 3 and 4 combined to scenario A): The overall risk is M during festival periods and L outside festival periods considering either of the two pathways for the exposure (direct or vector-borne).

Table 7 Definitions of the three levels of uncertainty considered for the study

Uncertainty	Description
High (H)	No or very sparse data, statement based on unpublished data or observations
Medium (M)	Some data are available but incomplete, some references available
Low (L)	Sufficient and complete data available, large number of references available

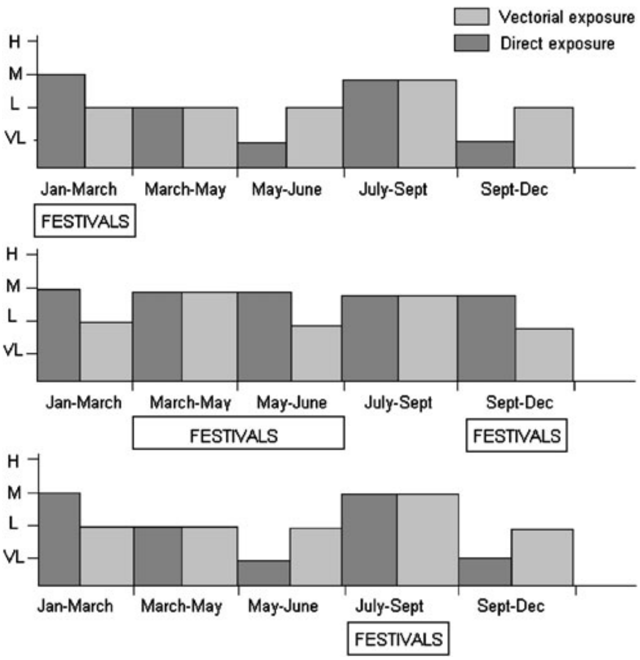

Fig. 4 Overall measure of the risk of introduction of RVFV from the Horn of Africa to Yemen

- From May to July and September to December (scenario 3 and 4 combined to scenario B): The risk increases from L to M during festivals if exposure occurs via the direct transmission pathway and from VL to L if exposure occurs via the vectorial transmission pathway.
- Finally, from July to September period during which it is the rainy season in the Horn of Africa but also a flooding period in Yemen (scenario 1 and 2 respectively combined with scenario A): The overall risk by either of the two pathways of exposure considered and either period of occurrence is M.

The final estimate of uncertainty was medium (low combined to high following Table 6).

Discussion

Yemeni Veterinary Services did not declare any RVF outbreak since 2000. However, literature suggested that the virus was probably present in Yemen before 2000 and that the combination of favourable factors—climatic and socio-economical—was responsible for the 2000 simultaneous outbreaks in Yemen and Saudi Arabia (Davies 2000; Madani et al. 2003). The results of the serological surveillance performed (between 2004 and 2008) by Yemeni Veterinary Services suggest that the virus did not persist or keep circulating at a very low level. A re-introduction of the virus during a favourable period in Yemen could then lead to a new outbreak.

This first qualitative analysis examined the main features likely to influence the risk of introduction of RVFV in Yemen. Even if the qualitative method has limitations especially regarding the choice of categories for the different parameters chosen, it is a valuable tool from a risk-management stand point (Shih et al. 2005). Thus, if the choice of the combination matrix by Zepeda may be criticable overestimating results if 'translated' in numerical terms, it still enables the comparisons of levels of risks across different scenarios. It appears that the risk considering direct transmission as an exposure route is always greater or at least equal to the vectorial one underlining the importance of quarantine and sanitary measures in order to mitigate it. The risk is also greater during the occurrence of the festival periods between when March to July and September to December. This study lets us underline gaps in information that could better inform whether the animals selected for trade may be viraemic, the Horn of Africa being one area where not much data is available (Clements et al. 2007); general paucity of data making a quantitative assessment of RVFV introduction in Yemen is poorly relevant. This work also points out the necessity of allocating more resources to improve the quarantine and testing system in order to adequately reduce the probability of introduction. The next step should be to quantify the probability of occurrence of each event and to perform a sensitivity analysis in order to provide adapted and targeted surveillance and/or control measures.

The risk question included only small ruminants which are the most susceptible species to RVF and thus the more likely to spread the virus. Including cattle or camels would not have fundamentally changed results as small ruminants are the species with the highest density all over the Horn of Africa and with the highest importance in terms of trade with Yemen either considering the quantities/volumes or values exchanged (FAO 2010). We did not consider other potential ways of virus introduction as infectious vectors, viraemic humans, animal products, fomites and vaccines (EFSA 2005); that should be taken into account in a future global assessment adding individual results together. Mosquito densities are huge during the Kenyan rainy season, and the distance between African and Arabian coasts is rather small: infectious vectors could cross this channel either by active flight—according to the study methods, the involved species and climatic conditions, the active flight capacities of *Aedes* and *Culex* species range from several meters to more than 10 km (Ba et al. 2006; Bogojevic et al. 2007)—by wind or by boat from Africa to the Arabic Peninsula.

The number of animals imported to Yemen from the Horn of Africa had a high uncertainty although it was minimized not considering illegal trade in the risk question expected to be even more important during festival periods

(Shih et al. 2005). Nevertheless, a precise estimate was not critical for the final results. However, it is extremely difficult to control illegal livestock trading especially from Somalia as the political situation is unstable in this region. Because of a total of 5,510 miles of coastlines when considering the Horn of Africa and Yemen, considering the illegal trade did not appear as a control point that could be considered and thus perhaps enlighten (Rotberg 2005).

To our knowledge, it is the first time a risk assessment of introduction of RVFV is conducted for Yemen. In the Middle East, a FAO report by Davies and Nunn (1998) considers an overall risk of RVF from livestock imported to the Kingdom of Saudi Arabia from the Horn of Africa as extremely low outside epidemic periods and high, otherwise, 10 years ago. Here, we also took into account the importance of the festival periods and of their changing occurrence dates along the years and our final estimates appear less extreme (VL to M) even if hardly comparable.

If pre-epidemic conditions have been recognised—in East Africa, a correlation between heavy rainfall events and outbreak occurrence has been clearly demonstrated (Linthicum et al. 1999)—disease risk can be substantially reduced if all animal-related trade with high risk countries is temporarily discontinued. Predictions produced by RVF models incorporating climatic data need to be used to inform these decisions (Anyamba et al. 2002). The main clinical sign of RVF is abortion while the most exported live animals are males (*Ram*), so improving the serological sampling could be theoretically a good way to improve the control of RVF at import (Davies and Martin 2006). Nevertheless when considering the amount of animals imported and the laboratory facilities in the region, the task becomes much less attractive. An effective and perhaps less costly solution would be ensuring an efficient quarantine in terms of isolation of the animals upon arrival and length of stay in the quarantine station that should be increased especially during the festival periods.

At a wider geographical scale, an EFSA report (2005) of the risk of a Rift Valley fever incursion in the EU and its persistence within the community, for example, concludes for the exposure assessment that the probability of introduction of infected live animals and contaminated animal products legally imported is negligible for sheep and goats, low for cattle, but likely to increase during epidemic periods in the source country. In the case of small ruminants, it is due to the fact that regions in which RVF is believed to be present do not overlap with the places from which the major legal importation takes place, and for cattle, to the import regulation and detection measures at EU entry that although they are not 100% effective, they considerably diminish the risk. It underlines the importance of effective mitigation measures and the necessity for a better knowledge of the current situation of the disease in the Horn of Africa for RVF but also for other highly transmissible disease that still highly shortcuts exportation possibilities such as Foot and Mouth disease or Peste des Petits Ruminants.

If the socio-economical impact of RVF is considered very important (Holleman 2002; ARD 2006; Soumare et al. 2007), a comprehensive evaluation of the impact of the disease in Yemen is to be undertaken and should help demonstrate the urgency of allocating enough resources to improve the surveillance and prevention of this disease.

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Conflicts of interest The authors declare that they have no conflict of interest.

References

Abd El-Rahim, I.H.A., El-Hakim, U.A., Hussein, M., 1999. An epizootic of Rift Valley fever in Egypt in 1997, Revue Scientifique et technique de l’Office International des Epizooties, 18, 741–748

Ahmad, K., 2000. More deaths from Rift Valley fever in Saudi Arabia and Yemen, Lancet, 356, 1422

Aklilu, Y., 2002. An Audit of the Livestock Marketing Status in Kenya, Ethiopia and Sudan. Volume II: Issues and Proposed Measures,(unpublished report, Community-Based Animal Health and Participatory Epidemiology Unit, Pan African Programme for the Control of Epizootics, Animal Resources, Nairobi, Kenya)

Alabsi, A.A., 2006. Yemen profile, (http://www.fao.org/ag/AGP/AGPC/doc/Counprof/Yemen/yemen.htm)

Alary, V., 2006. Etude du commerce régional du bétail et des produits animaux en Afrique de l’Ouest (zone ECOWAS) et Afrique de l’Est (zone IGAD), (unpublished CIRAD report for FAO, CIRAD, Montpellier)

Anyamba, A., Linthicum, K. J., Mahoney, R., Tucker, C.J., Kelley, P. W., 2002. Mapping potential risk of Rift Valley fever outbreaks in African savannas using vegetation index time series data (Special Issue: remote sensing and human health), Photogrammetric Engineering & Remote Sensing, 68, 137–145

ARD, 2006. Livestock movement and trade study for the Yemen agricultural support program, (unpublished report, USAID)

Ba, Y., Diallo, M., Dia, I., Diallo, M, 2006. Feeding pattern of Rift Valley fever virus vectors in Senegal. Implications in the disease epidemiology, Bulletin de la Société de pathologie exotique, 99, 283–289

Bogojevic, M.S., Hengl, T., Merdic, E., 2007. Spatiotemporal monitoring of floodwater mosquito dispersal in Osijek, Croatia, Journal of the American Mosquito Control Association, 23, 99–108

CDC, 2007. Rift Valley Fever Outbreak - Kenya, November 2006-January 2007, Morbidity and Mortality Weekly Rreport, 56, 73–76, http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5604a3.htm

Chevalier, V., Lancelot, R., Thiongane, Y., Sall, B., Diaité, A., Mondet, B., 2005. Rift Valley Fever in Small Ruminants, Senegal, 2003, Emerging Infectious Disease, 11, 1693–1700

Chevalier, V., Martin, V., De La Roque, S., Roge,r F.,2008. Combating and predicting Rift Valley fever: a scientific and geopolitic challenge for the future? In: ASM (eds), Emerging Infections 8, Washington, 2008, (ASM press).

Clements, A.C.A., Pfeiffer, D.U., Martin, V., Otte, M.J., 2007. A Rift Valley fever atlas for Africa, Preventive Veterinary Medicine, 82, 72–82

Daubney, R., Hudson, J.R., Garnham, P.C., 1931. Enzootic hepatitis or Rift Valley fever: an undescribed disease of sheep, cattle and man from east Africa, Journal of Pathology and Bacteriology, 89, 545–579

Davies, F.G., 2000. Rift Valley Fever in Yemen. Roma: Food and Agriculture Organization.

Davies, F.G., Nunn, M.J., 1998. Risk of Rift Valley fever from livestock imported into the kingdom of Saudi Arabia from the Horn of Africa, (unpublished FAO report, Rome)

Davies, F.G., Martin, V., 2006. Recognizing Rift Valley fever, Veterinaria Italiana, 42, 31–53

Dirie, M.F., Wais, E.I., 2005. Preliminary study on livestock marketing in Somaliland. (unpublished FAO report, Rome)

EFSA, 2005. The risk of Rift Valley fever incursion and its persistence within the Community, The EFSA Journal, 238, 1–128

FAO 2010. FAOSTAT database, http://faostat.fao.org/site/291/default.aspx

Gebreegziabher, B., 2008. In: ProMed, Disease report, animals - Ethiopia: (south) (02), N°20080309.0966, published 09/03/2008, http://www.promedmail.org/pls/otn/f?p=2400:1202:3575989784933679::NO::F2400_P1202_CHECK_DISPLAY,F2400_P1202_PUB_MAIL_ID:X,71765

Gerdes, G.H., 2004. Rift Valley fever, Revue Scientifique et technique de l'Office International des Epizooties, 23, 613–623

Holleman, C., 2002. The socio-economic implications of the livestock ban in Somaliland, (Food Early Warning System, Assessment Mission to Somaliland, FEWS NET: Nairobi).

InVS. 2007. Cas importé de Fièvre de la vallée du Rift, (Unpublished report of the Institut de Veille Sanitaire (InVS), Paris)

Kasari, T.R., Carr, D.A., Lynn, T.V., Weaver, J.T., 2008. Evaluation of pathways for release of Rift Valley fever virus into domestic ruminant livestock, ruminant wildlife and human populations in the continental United States, Journal of the American Veterinary Medical Association, 232, 514–529

Ksiazek, T.G., Jouan, A., Meegan, J.M., Guenno, B.L., Wilson, M.L., Peters, C.J., Digoutte, J.P., Guillaud, M., Merzoug, N.O., Touray, E. M., 1989. Rift Valley fever among domestic animals in the recent West African outbreak, Research in Virology, 140, 67–77

Linthicum, K.J., Anyamba, A., Tucker, C.J., Kelley, P.W., Myers, M. F., Peters, C.J., 1999. Climate and satellite indicators to forecast Rift Valley fever epidemics in Kenya, Science, 285, 397–400

Madani, T.A., Al-Mazrou, Y.Y., Al-Jeffri, M.H., Mishkhas, A.A., Al-Rabeah, A.M., Turkistani, A.M., Al-Sayed, M.O., Abodahish, A. A., Khan, A.S., Ksiazek, T.G., Shobokshi, O., 2003. Rift Valley Fever Epidemic in Saudi Arabia: Epidemiological, Clinical and Laboratory Characteristics, Clinical Infectious Diseases, 38, 1503

Nabeth, P, Kane, Y., Abdalahi, M.O., Diallo, M., Ndiaye, K., Ba, K., et al., 2001. Rift Valley fever outbreak, Mauritania, 1998: seroepidemiologic, virologic, entomologic, and zoologic investigations, Emerging Infectious Disease, 7, 1052–1054

Rotberg, R.I., 2005. The Horn of Africa and Yemen, diminishing the threat of terrorism. In: Rotberg RI (ed), Battling Terrorism in the Horn of Africa, Washington, 2005, (World Peace Foundation: Brookings Institution press)

Saeed, K., 2008. RVF Control Strategy for flood affected Areas of Somalia, (Report for Food and Agriculture organization (FAO), Roma)

Shih, T.H., Chou, C.C., Morley, R.S., 2005. Monte Carlo simulation of animal-product violations incurred by air passengers at an international airport in Taiwan, Preventive Veterinary Medicine, 68, 115–122

Shoemaker, T., Boulianne, C., Vincent, M.J., Pezzanite, L., Al Qahtani, M.M., Al Mazrou, Y., Kahn, A.S., Rollin, P.E., Swanepoel, R., Ksiazek, T.G., Nichol, S.T., 2002. Genetic analysis of viruses associated with emergence of Rift Valley fever in Saudi Arabia and Yemen, 2000–2001, Emerging Infectious Diseases, 8, 1415–1420

Soumare, B., Tempia, S., Cagnolati, V., Mohamoud, A., Van Huylenbroeck, G., Berkvens, D., 2007. Screening for Rift Valley fever infection in northern Somalia: A GIS based survey method to overcome the lack of sampling frame, Veterinary Microbiology, 121, 249–256

Tesh, R.B., Travassos da Rosa, A., Guzman, H., Araujo, T.P., Xiao, S. Y., 2002. Immunization with heterologous flaviviruses protective against fatal West Nile encephalitis, Emerging Infectious Diseases, 8, 1392–1397

Thonnon, J., Picquet, M., Thiongane, Y., Lo, M., Sylla, R. and Vercruysse, J., 1999. Rift Valley fever surveillance in the lower Senegal river basin: update 10 years after the epidemic, Tropical Medicine and International Health, 4, 580–585

WHO, 2007a. Outbreaks of Rift Valley fever in Kenya, Somalia, and United Republic of Tanzania, December 2006–April 2007, Weekly epidemiological record, 82, 169–180

WHO, 2007b: Rift valley fever in Sudan-Update 4, (http://www.who.int/csr/don/2007_11_05/)

WHO, 2007c. Rift Valley fever, (http://www.who.int/mediacentre/factsheets/fs207/en/)

Wilson T., Dioli M., Helland J., Stockton G., Siddiqui A., 2004. Somalia: Towards a Livestock Sector Strategy, (unpublished Final Report, FAO, Rome, http://siteresources.worldbank.org/SOMALIAEXTN/Resources/so_LS_final_rpt.pdf).

Zepeda, C., 1997. Méthode d'évaluation des risques zoosanitaires lors des échanges internationaux,(Séminaire sur la sécurité zoosanitaire des échanges dans les Caraïbes, Port of Spain)

Chapter 7: Discussion and Perspectives

6 Synthesis

In September 2000, a major outbreak of RVF was reported for the first time in Yemen and Saudi Arabia. This outbreak opened a new era of the epidemiology of the disease, demonstrating that the virus has the capability to spread to new areas from its endemic zone where it was first identified in 1930.

In this thesis, the outbreak of RVF in Yemen was studied in relation to different aspects: the global socio-economic impact of RVF, the descriptive epidemiology of RVF in Yemen, the environmental and socio-economic risk factors related to RVF occurrence and the risk assessment of the re-introduction of RVF from the Horn of Africa via legal trade of small ruminants.

Following a detailed state-of-the-art on RVF epidemiology (Chapter 1) and a geographic presentation of Yemen (Chapter 2), the socio-economic impact of RVF in Yemen was examined in Chapter 3, highlighting the dramatic socio-economic impacts of the disease, including its impact on the markets as well as on the subsistence of pastoralists as compared to other diseases.

The epidemiology of the RVF outbreak in Yemen, 2000-2001, was extensively studied in Chapter 4 at two scales: the national level scale and the local scale in the Wadi Mawr (Tihama plain). This study highlighted a spatial heterogeneity in the cases distribution, related to the irrigation scheme.

After 2001, no new RVF outbreak was detected in Yemen. Thus, the objective of Chapter 5 was to assess whether the year 2000 was different -and in which aspects- as compared to others recent years (1999-2007). A major conclusion of this study is that the conjunction of two rainy seasons presenting above-normal precipitations and a starting date for the Eid-al Kabeer festival occurring in spring seems to have contributed to the emergence of RVF in 2000 in Yemen.

Thus, assuming that the virus has not survived in Yemen after 2001, we assessed the risk of re-introduction of RVF into Yemen via the legal trade of small ruminants from the Horn of Africa (Kenya, Somalia, Djibouti, and Ethiopia), in the Chapter 6. Using assumptions for the introduction scenarios, the probability of pathogen introduction and the probability of exposure of susceptible animals in Yemen was assessed qualitatively following the OIE risk assessment framework and found very low to medium depending on the period of the year. The uncertainty was considered to be low.

The main findings of these different studies led us to propose a general scheme of the ecology and transmission patterns of RVF in Yemen.

7 Main results

7.1 Socio-economic impacts

What was the socio-economic impact associated with this outbreak?

Despite of the difficulty to estimate precisely the global socio-economic impact of outbreaks of RVF in different regions in the world, our study highlighted it was very high especially in the Horn of Africa (FEWS.Net 2000; Holleman 2002; Soumaré, Thys et al. 2006; FEWS Net 2007; Wanyoike and Rich 2008; Soumare, Tempia et al. 2007). Thus RVF is a major threat for the Horn's pastoralists. The disease also threatens the livestock trade in whole region including the Middle East. The outbreaks in the Somalia area (1997-87) and in the Arabic peninsula (2000) showed it could also affect the economical stability of whole governements like that of Somali land (Ahrens 1998; Holleman 2002). The recent outbreak of 2006-2007 in East Africa seriously impacted food security with a socio-economic impact of 3 993 821 577 KS ($51 733 440) in Kenya for example according to (Wanyoike and Rich 2008).

In Yemen the RVF outbreak in 2000-2001 led to dramatic socio-economic impacts affecting all the sectors of life associated to livestock activities (breeding, animal trading, meat processing) as well as the human health. There were many human cases and mortility as well as animal cases (Al Qadasi 2002; Handlos 2009). Indirect effects lasted for a long time necessary to recover from the livestock losses and to re-gain the consumers' confidence. Thus, the livestock in this region is a source of stability and acts as a reserve bank for the poor pastoralists. The financial lost was estimated as $15 268 176.

This study also highlighted the need for information and techniques for evaluating socio-economic losses due to RVF in particular and animal diseases in general.

7.2 The ecology and mechanisms of RVF emergence in Yemen

Why did the epidemics occur in the Tihama region (western coast) of Yemen?

The descriptive study of RVF outbreak in Yemen, 2000-2001, highlighted the relationship between the occurrence of RVF and the presence of irrigated areas. Indeed, in Yemen most of the animal disease's outbreaks occurred in the *wadis*, the agricultural valleys with irrigated schemes. Moreover, areas with similar environmental conditions (high rainfall and high NDVI values), for example catchment areas located in the mountains, remained free of the disease .The irrigation spates which were established in 1986 in the large *wadis* in Yemen, like Wadi Mawr (Figure 17), resulted in changes in the *wadi* ecosystem, making it an ideal breeding site of mosquitoes *Aedes* and *Culex* (Jupp, Kemp et al. 2002; Miller, Godsey et al. 2002). This hypothesis is consistent with observations made in Egypt, Senegal and Mauritania, where the irrigation projects played a role in outbreaks occurence, like outbreaks of 1977 in Egypt (Meegan, Moussa *et al.* 1978), and 1987 in Senegal and Mauritania (Saluzzo, Chartier et al. 1987; Saluzzo, Digoutte et al. 1987).

Thus, the *wadis* may be considered as risk areas for RVF in the future. In terms of epidemiological processes and ecology, we may assume that in Yemen, two different above-mentioned patterns are represented: irrigated areas (Mauritania 1987, Egypt 1977) and temporary ponds areas, as the sudden filling of *wadis* may be rather favourable to *Aedes* mosquito proliferation. As a matter of fact, entomological knowledges are lacking, and our assumptions need to be reinforced by field entomological studies and ecological modelling.

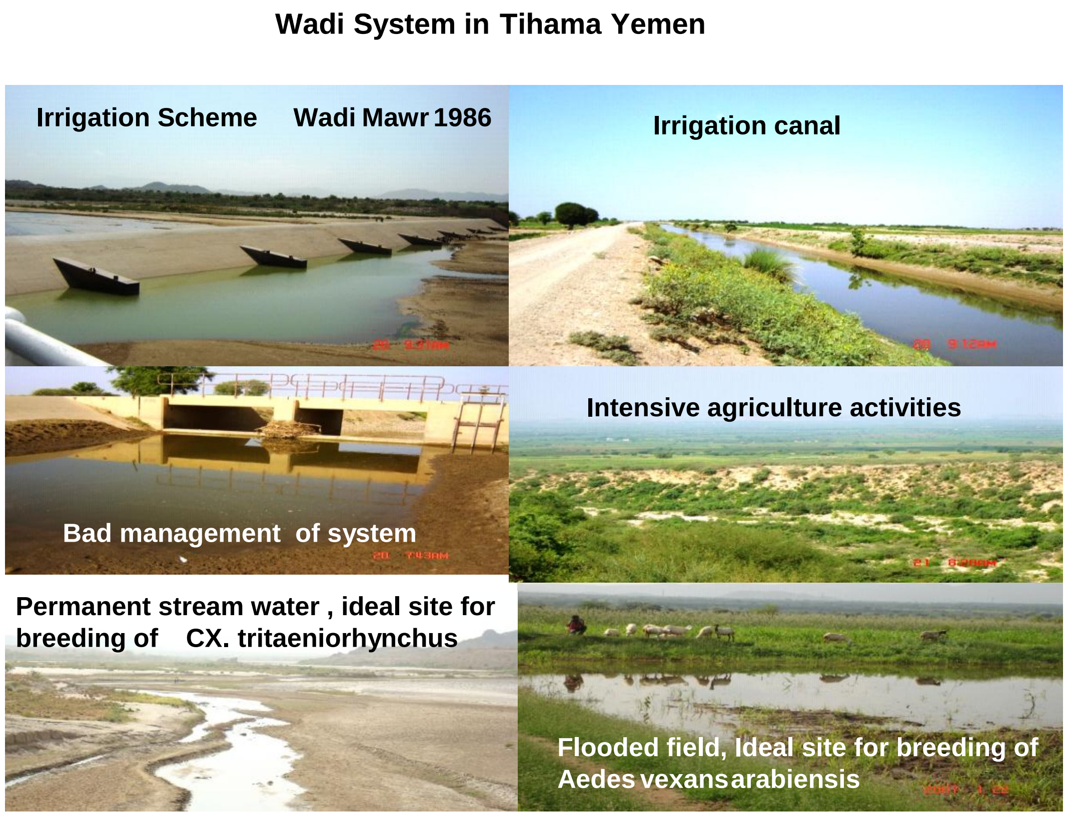

Figure 17: Different *wadis* of the Tihama Coast

Why did the disease start in Wadi Mawr and is not in other *wadis*?

According to our retrospective descriptive study, the outbreak started near the irrigation spate of Wadi Mawr. Then, it spread towards northern *wadis*, namely Hajjah, Harad, Nakalah and Sadah, then towards the southern *wadis*. The last case was near Wadi Zabeed, 200 km southern of Wadi Mawr (Davies 2000).

In the case of the irrigation spate of Wadi Mawr, the intensive development of agricultural activities and the establishment of new settlements along the valley could have played a major role in the 2000-2001 outbreaks. Indeed, livestock trade has greatly increased in this last decade in this region. Moreover, the Wadi Mawr has a privilegiate place for animal importation from the Horn of Africa, as the sea port Al-Luhyah on the western coast of the Red Sea is located at only 30 km of the Wadi Mawr.

Most of the cases were located near the northern canal as compared to southern canal of the irrigation scheme of Wadi Mawr (Abdo-Salem, Gerbier et al. 2006). The water management could be one of the reasons due the bad maintenance and water management of the canals (Figure18). The presence of regularly flooded areas provides a suitable environment for the hatching of the eggs of *Aedes* mosquitoes. It is likely that the bad management of the network of the irrigation scheme resulted into the creation of ponds with stagnant water, which are the ideal breeding sites for *Culex* populations.

Nevertheless, to conclude on the risk for the Wadi Mawr in comparison to other *wadis* from the Tihama coast, additional field studies (entomology, serosurveillance) are needed.

Why did the outbreak occur in 2000 and not in 2006-2007?

The question of RVF emergence in Yemen in 2000 is crucial. 264 samples from serumbank was collected in 1996/97 from the outbreak area of RVF in 2000. Retrospectively retested by ELISA to screen the presence of RVFV IgG all samples were negative (Al Qadasi 2009) suggesting that RVF virus did not circulate in this area before 1998..

The drivers of an emerging disease occurring for the first time in a formally disease-free region are difficult to determine. Indeed, by definition, outbreaks are rare and few epidemiological data are available, as it is the case for the unique RVF outbreak in Yemen in 2000-2001.

To assess whether the year 2000 was different -and in which aspects- compared with others recent years (1999-2007), we performed an analysis taking into account socio-economical and environmental variables related to each of the three components of the epidemiological cycle: host, vector and virus:

Taking into account the environmental conditions only, this descriptive approach demonstrated that the year 2000 was not significantly different from the others years of the (1999-2007) period. However, the second analysis which took into account environmental and socio-economical factors highlighted that 2000 was atypical from all the other years in respect to two main factors:

i) The characteristics of NDVI peaks (maximum values for both rainy seasons),

ii) The starting date of Eid-al Kabeer festival

What mechanisms could explain the 2000 emergence in Yemen?

These results led us to propose the following sheme for RVF emergence in Yemen in 2000 (Figure 18): the concentration of livestock at the occasion of Eid-al Kabeer celebration, relatively late in the year (March) occurred at the early beginning of the first rainy season, which was characterized by important precipitations favourable to high *Aedes* vector densities. This allowed the amplification of the transmission cycle and the persistence of virus transmission at low level between the two rain seasons, probably due to the residual dry season *Culex* population. As the second rainy season presented also high level of precipitations and thus high vector densities-mixing *Aedes* and *Culex* mosquitoes, the RVF transmission cycle may have been reinitiated in autumn with the rain, at high level of transmission, leading to the declared outbreaks in September.

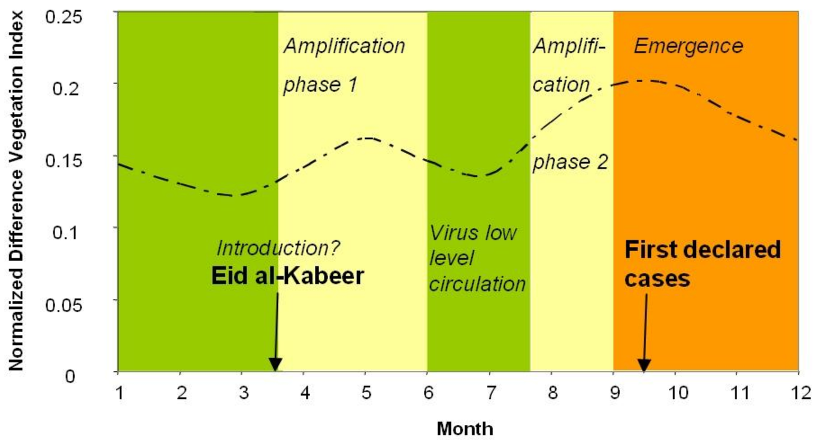

Figure 18: Schematic representation of the RVF virus amplification and emergence in Yemen, 2000.

Nevertheless, our results should be taken with caution because of the limited number of years considered and the lack of knowledge on the mosquito population present in this area.

Yemeni Veterinary Services did not declare any RVF outbreak since 2000. Whether RVF virus survived in Yemen after the 2000 outbreak remains unknown. Due to very dry and hot conditions, it likely did not, except in the case of vertical transmission. Thus, we assumed Yemen free of the disease after 2000. As RVF is endemic in the Horn of Africa, the risk of re-introduction in the Arabic Peninsula remains. According to the results of the epidemiological studies, the following conceptual model for RVF transmission in Yemen is proposed (Figure 19):

The introduction of RVFV in Yemen may occur by the introduction of a viremic animal from RVF endemic zones in the Horn of Africa, through animal trade. This introduction probably takes place during the high peak period of animal importations, *i.e.* Ramadan and Eid Festival.

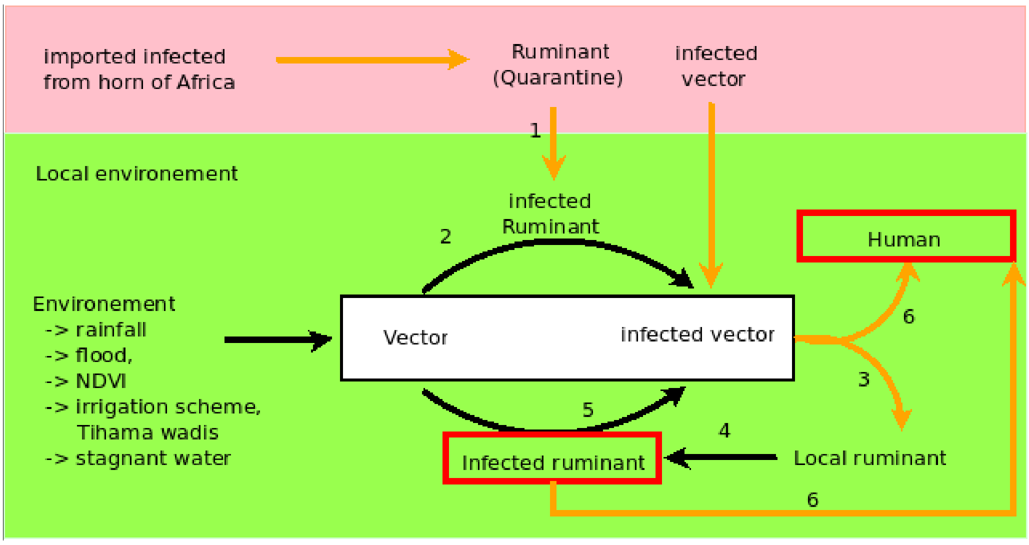

Figure 19: Conceptual model of RVF transmission in Yemen

Animals rest in quarantine only a few days and are rapidly transported to the Tihama *wadis* (1). The duration of the transportation of one animal from its origin zone to the *wadis* is less than the incubation period. If the date of Eid Festival in Yemen is held during the first rainy season (March –May), when the environmental conditions are favourable to vector populations, then the RVFV will be transmitted to the vector population (2) and in turn to local ruminants (3). Once infected, local ruminants will transmit RVFV to mosquito again, leading to the amplification of the transmission cycle between the two rain seasons (4, 5).

If the second flood period (July –October) is also highly favourable to the development of vectors, the high populations of *Aedes* and then *Culex* mosquitoes will lead to remergence of RVF (6).

Thus, the periods at risk for RVF in Yemen could be described following the conceptual calendar depicted in (Figure 20).

- The climate patterns in the Horn of Africa plays very important role of the re-emergence of RVF in Yemen when the first and second rainfall seasons in the Horn of Africa and the religious festival in Yemen fall in the same period of the first rainy season from Mars to May.
- The pattern of the second rainfall season July to October in Yemen and flood of Wadis in Tihama coast has closed association with the re-emergence of RVF.
- The level of NDVI during the two rainy seasons correlated with rainfall and flood of Wadis and propagation of the vectors.
- The activity and propagation of the vectors *Aedes* and *Culex* will be intensively increased. The highest risk period will be between August and October.

All of these factors should be taken into account for the implementation of early-warning systems in Yemen.

If these pre-epidemic conditions have been recognised, prevention measures must be applied to avoid re-emergance of the disease.

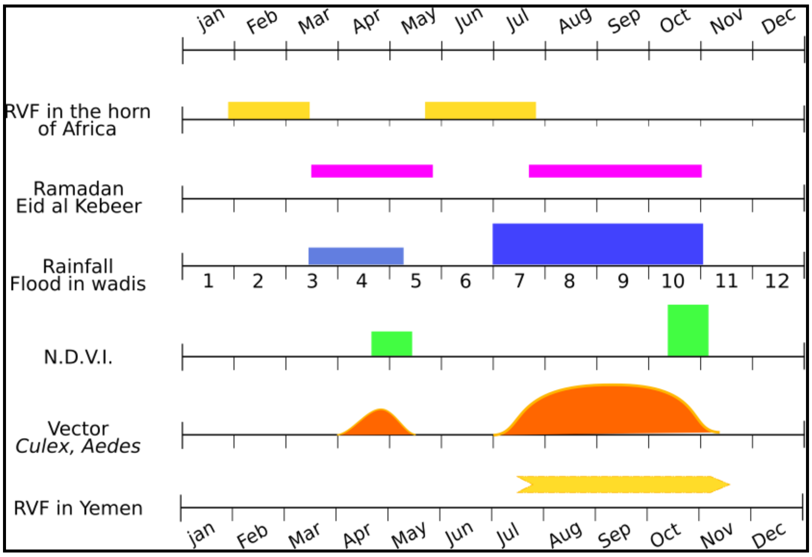

Figure 20: Time-conceptual model of RVF introduction in Yemen from the Horn of Africa.

7.3 The introduction of the RVFV in Yemen from the Horn of Africa

The introduction of RVFV in Yemen in 2000

Livestock trade between the Horn of Africa and the Arabic Peninsula has a long and traditional history. Indeed since the past 70 years before the 2000-2001 outbreaks in Yemen, millions of animals have been entering Yemen and Saudi Arabia and there are millions of human exchanges between the Horn of Africa and Middle East.

During the 20^{th} century, there has been an increase in animal trade due to major socio-economic changes in the Middle East (wealth of petrol, development and increase of urban populations). All of these factors, in association with a greater consumption of livestock products (in particular meat live animals), emigration and climatic changes in the region, have contributed to a great increase of exchanges between Yemen and the Horn of Africa. It is essential to take into account that RVF is endemic in East of Africa since 70 years.

The hypothesis of introduction of RVFV to Yemen from the Horn of Africa is strengthened by phylogenetic analysis of the virus isolated in Saudi Arabia and Yemen, showing a high homology with the strains isolated in Kenya in 1997/1998 (Shoemaker, Boulianne et al. 2002; Bird, Khristova et al. 2007). This suggests that the virus could have been introduced to the Arabic Peninsula from the East of Africa along with animal trade (Balkhy and Memish 2003; Bird, Khristova et al. 2007).

Nevertheless, during the outbreak period of 2000-2001, neither epizootics nor epidemics were declared in the Horn of Africa. It is possible that viremic animals were imported into Saudi Arabia or Yemen after the 1997-98 East african epizootics and that the virus was circulating at low level without being detected (Davies 2000; Balkhy and Memish 2003). Another hypothesis for the introduction into the Arabic Peninsula could be the dispersal of infected mosquitoes carried out into the Arabic Peninsula by low level air current from the area of epizootic activity in the Horn of Africa in 1997-98 (Davies 2000).

What is the risk of re-introduction of RVF from the Horn of Africa through legal importation of livestock?

As previoulsy mentioned, we assumed that the virus did not survive after the 2000 outbreak. To evaluate the risk of re-introduction of RVFV in Yemen, a qualitative risk assessment method was used in Chapter 6. If the qualitative method has limitations especially regarding the choice of categories for the different parameters chosen, it is a valuable tool from a risk-management stand point (Shih, Chou et al. 2005). To our knowledge, it is the first time a risk assessment of introduction of RVFV is conducted for Yemen.

This analysis indicated that the risk of re-introduction of RVFV to Yemen is high, taking into account the activities having occured these last years in the endemic zone of the East of Africa.

According to the serological surveillance conducted by the Yemen Veterinary Services, no outbreak was declared since 2001, except a few samples of IgG and IgM sero-positive.

In 2007, 10 samples IgM were found positive, 7 of them from Mukkah quarantine. These observations confirm the risk of introduction of infected animals via the trade with the Horn of Africa, as it was following a RVF outbreak in 2006- 2007 in East Africa. At this time, Yemen banned the import of livestock from the Horn of Africa but for a short period only. The outbreak in East Africa was not followed by any outbreak in Yemen, while thousands of animals were already imported into the local markets (Al Qadasi 2009).

In 2008, all environmental factors were favourable for RVF outbreak in Yemen, like in 2000. Thus, the epidemiological units in Yemen started in collaboration with experts of CIRAD, FAO and NASA (risk maps were provided by NASA) to target the surveillance in all zones at risk. Fortunately, in the field all the sero-surveillance samples were negatives.

This emphasis that the predictive model developed on the Horn of Africa is not sufficient to predict RVF outbreak in the case of Yemen. These conclusions are coherent with our study on the role of socio-economic as well as environmental factors in the 2000 outbreak. Again, more investigations with field results are needed to propose an early-warning system adapted for Yemen.

Additional elements concerning the introduction and re-introduction of RVF to Yemen

The high cattle densities in this region as well as the high number of commercial exchanges remain important risk factors for the introduction of RVFV in Yemen:

- The animal population in East Africa is the largest in Africa and for some species (*e.g.* camels in Somalia, Sudan, Ethiopia, Kenya Eritrea and Djibouti) the largest in the world (Figure 21)

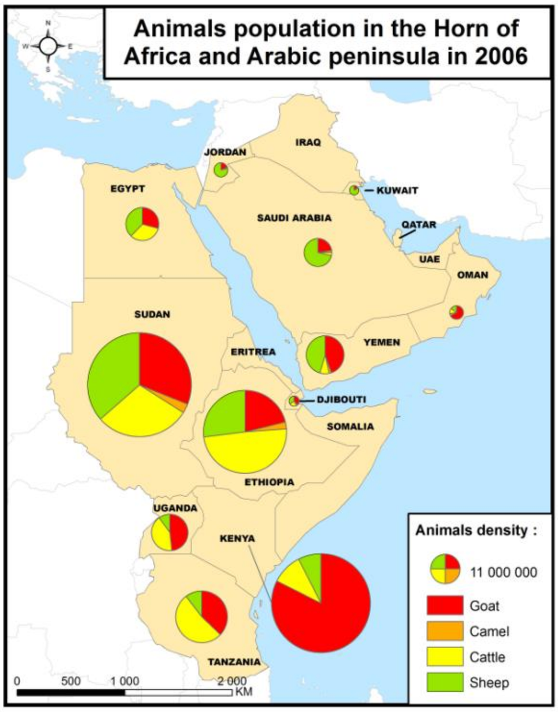

Figure 21: Livestock population in the Horn of Africa and Arabic peninsula in 2006

- The Horn of Africa and the Arabic Peninsula are together the biggest zone of animal trade in the world during all along the year, and particularly during religious festivals (Ramadan, Eid-Al-adha, pilgrims in Mecca) when millions of animals are sacrified on a few days;
- Most of importations of live animals in Yemen come from the Horn of Africa: Yemen is the main importer of small ruminants from Somalia and of cattle from Ethiopia. Some of these imported animals originate from North-Eastern of Kenya which is an endemic zone for RVF;
- Animal trade has deep roots in families on both sides of the Red and Arabian Seas;
- From 1972, after the outbreak of Rinderpest in Yemen, the number of importations of live animals to Yemen increased due to the high mortality of local animals; it also increased significantly after the reunification of Yemen in 1990. Since 1995, the imports of livestock to Yemen have been increased by 643% (ARD 2006);
- In general in the Middle East, infected animals can move easily from one country to another (Shimshony and Economides 2006);
- The political situation in Somalia since the beginning of civil war in 1991 made the refugee number increase in Yemen. They enter through the eastern coast at the rate of about 3000 persons per month (Shiil 2008).

Moreover, the geographic position of Yemen in relation to the Horn of Africa favors legal as illegal trade between the two regions:

- Yemen has a very long sea coast (more than 1900 km) in the Red Sea and the Arabian Sea and smuggling and illegal animal trade is common;
- The time for crossing the sea between the Horn of Africa and the Arabic Peninsula with sea boats is less than 2 days (Aklilu 2002). Thus, infected animal can arrive to Yemen during the incubation period of RVFV considering such short distance between Somalia and Yemen.

It should also be noted that the quarantines in the Horn of Africa and Yemen have no good infrastructure (ARD 2006) and may not have the sufficient equipment to control imported animal for RVF. It seems that in most of the cases the animals rest less than the incubation period of RVFV.

The quarantine measures taken are very lax in the quarantines on the both sides of the Horn of Africa region except in Djibouti where quarantine, launched in 2006, fulfils the market demand of Saudi Arabia only. Being a small country, Djibouti can not serve as a base for the export of animals of the whole region and moreover the cost of the quarantine results in an increase of the animal prices not always advantageous. Almost 90% of the animals imported to Yemen come through Somalia. The animals rest only for a few days in quaratines before exporting to Yemen, and this period is less than the incubation period of RVFV. During the high peak period of the import to Yemen the animals are brought in through the Somali middlemen who collect animals from different markets even as far as south-western Kenya, which is an endemic zone of RVF. Additionally, the animals pass through different local markets in Somalia before being exported to Yemen. The distance is covered in less than two days which is less than the incubation period of RVFV. In Yemen the quarantine facility needs capacity building. The animals rest there for less than 21 days depending upon the market demand especially during the high peak period of religious festivals. After the arrival into the quarantine, the local traders buy the animals and the animals are passed through different markets in Tihama before being distributed to different markets though out Yemen.

Finally, some experts indicated that the ecology of the Tihama coast presents similarities with the other coasts in the Horn of Africa, where RVF is endemic (G.Davies, personal discussion). Moreover, the *wadis* of Tihama Coast are endemic zones for malaria, thus favourable to the development of mosquitoes (at the beginning of the RVF outbreak, the disease was confused with malaria which is endemic in the area; before the huge waves of animal abortions led to the suspicion of RVF).

Although the mode of introduction of the virus in Yemen has remained unclear until now, the importance of the livestock trade between Yemen and the Horn of Africa as well as the environmental conditions on the western coast of Yemen could be considered as the main risk factors indicating that a risk of re-introduction of RVFV to Yemen is high, taking into account the ongoing activities in the endemic zone of the East of Africa in the past years.

8 Implications for policy

What are the surveillance and control measures that should be taken after this outbreak?

In Yemen, the outbreaks of RVF led the decision makers to draw attention to the importance of veterinary medicine and to the socio-economic impact of the zoonotic diseases. It resulted into an improvement of the cooperation between the veterinary services and the human health.

The main clinical sign of RVF is abortion while most exported live animals are males so improving the serological sampling could be theoretically a good way to improve the control of RVF at import (Davis and Martin 2006). Nevertheless when considering the amount of animals imported and the laboratory facilities in the region, the task becomes much less attractive. An effective and perhaps less costly solution would be ensuring an efficient quarantine in terms of isolation of the animals upon arrival and length of stay in the quarantine station that should be increased especially during the festival periods.

The risk assessment underlines the importance of effective mitigation measures and the necessity for a better knowledge of the current situation of the disease in the Horn of Africa for RVF but also for other highly transmissible disease that still highly shortcuts exportation possibilities. It lets us underline gaps in information that could better inform whether the animals selected for trade are viremic, the Horn of Africa being one of the areas where not much data is available (Clements, Pfeiffer et al. 2007). It also points out the necessity of allocating more resources to improve the quarantine and testing system in order to adequately reduce the probability of introduction to an acceptable level. Finally it allows prioritizing periods during which surveillance and mitigation measures should be strengthen.

9 Perspectives

A counterpart of the dramatic socio-economic impact left by the outbreak of RVF in 2000-2001 in Yemen was that it led to a greater attention from the government to develop Yemen veterinary services. On the other hand, it also resulted in the development of closer cooperation with human health care professionals especially the epidemiologists and public health department poeple to work together to control and fight zoonotic and transboundry diseases. It opened collaboration between the ministry of health and veterinary services similar to the strategy of the international human and animal organizations WHO, OIE and FAO, joining hands for “One Health”. The best examples of the collaboration are a malaria program for fighting the vectors in Tihama, and a program fighting avian influenza H5N1 built with the ministry of health. Moreover, it has improved the skills and the experience of the epidemiologists working in the epidemiology unit of Sana’a and Tihama province as well has led to the opening of new units in the other districts (in the governorates of Al-Hodaidah, in the Tihama part of Hajjah and Sadah). The teams covered all villages and reported every single aborted case. In addition, the National Veterinary laboratory in Sana’a expanded, with a new P3 laboratory being established with the support of the IAEA (International Atomic Energy Agency) and the World Bank.

Since 2000 there has been targeted sero-surveillance in all risk areas affected in the last outbreak but more surveillance is needed in the quarantines and at other entering points of livestock.

Since 2006, sentinel herds were placed in high risk areas (Figure 22) but their number is not sufficient, therefore more sentinel herds should also be placed near to northern and southern Tihama *wadis* (valleys).

There are still multiple needs:

The epidemiological unit number should be increased and cover the entire main districts of Tihama, particularly closed to livestock markets.

- To improve active animals’ surveillances in all the coast of Tihama.
- To monitor the climatic situation rainfall, flood, NDVI, SST, humidity, ground temperature.
- To monitor and investagion of the vectors activities in high risk zones in all Tihama Wadis as well as the Eastern coast.
- To strengthen the quarantine measures, mainly during the high peak period of the livestock’s trade during the religious festival from Ramadan up to Eid Al-Kabeer and

canalising the entery of all the livestocks and animals products through the official quarantines.

- To improve the capacity building, expansion and modernization of the three main quarantines: Al-Mukah, Aden and Al-Mukallah, as well as improving the human skills.
- The establishment of more diagnostic labs in Tihama coast and improver human skills.
- The establishment of rapid detecting febrile camera test if possible for early detecting sicks animals at the entery in the quarantines.
- Follow up the RVF regional situation in Horn of Africa and Arabic Peninsula.
- Follow up the regional climatic situation, drought and El-Nîne phenomena in East Africa.
- The establishment of RVF surveillances database inculiding, rainfall, flood, NDVI, temperature, humidity, SST, numbers of the livestocks imported and exported and animals density.
- Installations of computer-aided spate management of the limited spate water resources in Tihama *wadis* for prevention of sedimentations and trash as well as maintenances of siphons for aviating of accumulation of the stagnant water and artificial ponds which are ideal sites for mosquito's propagation.
- To improve regional collaborations, exchange of information; organizing workshops and scientific meetings to develop a regional approche.
- To control of illegal livestock trade.
- More training and workshops for improving the skills of expertise, epidemiologists, virologists, entomologists, climatologist, geographers and technicians.
- More researchers in human side must be established in considering to the last outbreak very or rare studies were conducted about the disease.
- The development of communication and extension for awareness farmers, livestock breeders and traders regarding human health and socio-economic impact of transboundry diseases.
- The establishment of RVF regional network under the umbrella of international agencies.
- Coordination between all actors' international organizations, national VS, ONGS.
- Increasing the numbers of references labs (OIE twining labs).

- To improvement of the reporting system and transparency regarding the outbreaks in the region.

The geo-political situations of the Horn of Africa have great influence on the livestock trade in the region. Ever since the independence of Eritrea from Ethiopia in 1993, Eritrea blocked the Ethiopian access to sea through the Eritrean sea ports. However, this problem has a long history as far as the Italian colonization in1890. Due to this problem between the two nations, Ethiopia to be forced to negociate with Djibouti to export their products and in particular their livestock. That means high losses by paying taxes to get their products to the sea as well to export the livestock through Berbera and Bossaso ports of Somaliland to Yemen, Yemen being the main importer of cattle from Ethiopia.

However since the fall the regime of Said Barre in 1991 there is no stable central government in Somalia. In 2006 a modern quarantine was launched in Djibouti under the supervision of the OIE and the FAO for the export of livestock to the Middle East in particular to Saudi Arabia. Recently in February 2009 a new quarantine was also opened in Berbera in Somaliland with investments from Saudi Arabia. The facility is expected to quarantine to 1.5-2 million animals per year for export to the Middle East. Quarantine near to Djibouti border in Ethiopia is also under construction. All these quarantine constructions will have an impact on the pattern of the RVF circulation in the region. If the quarantines work efficiently, it will reduce the risk of spread of RVF towards the Middle East as these were the main entry points for the outbreaks of RVF in Saudi Arabia and Yemen in 2000. The last outbreak of 2006-2007 in East Africa forced international organizations, governments and country importing goods from the area like Saudi Arabia, Djibouti, and Somaliland to give more attention to the livestock trade. To my knowledge until now there is no P3 laboratory in the whole region and the capacity building of the existing laboratories is not up to the standards for the diagnosis of zoonotic diseases and the testing of millions of animals for RVF during a short peak period during the religious festivals of Ramadan, Eid Al-Fater and Eid Al-Kabeer. As 95 % of the imported animals are male while the main clinical sign of RVF is abortion, there is a real need for a laboratory test-based diagnosis. For this reason the establishment of an RVF network has a great importance as it could also serve for the control of other transboundary zoonotic diseases and could contribute to the improvement of the animal trade between the Horn of Africa and the Middle East. Considering sero- surveillances in field, the predictive model is used as an early warning system and works very well in East Africa, however needing a rapid response from the country at risk of outbreak. During the outbreak of 2006- 2007 the alert was given about two months before the outbreak occurred but the response came too late and it had a very heavy socio-economic impact. It could have been diminished and perhaps even avoided if the precautionary measures had been taken early enough. In addition to the predictive modeling, the use of results from sentinel herds in field could improve risk prediction.

RVF control can not be possible on the basis of efforts from individual countries. It needs a closer regional as well as international cooperation. This is also true for the control of other zoonotic diseases.

The Horn of Africa being the largest zone of livestock trade in the world, if disease control is achieved it could tremendously improve the living standards of the population of the region, as livestock trades are the back bone of their economy. Thus, there is really a need to work together in order to improve human and animal health in the region.

Yemen is not using vaccination to control RVF but it applies active surveillance in targeted risk areas using few sentinel herds as indicators for the circulation of the virus (Figure 22).

Figure 22: Sites of sentinel herds in Tihama

Regarding vector control, veterinary services and quarantine professionals benefit from the Malaria control program which has used twice a year indoor residual spraying (IRS) for 160 villages on the Tihama Coast the past 3 years. Malaria having been reduced by 75% in Tihama (Globalfund 2006), this practice seems to be efficient in fighting against the vectors for the moment. However a surveillance study is greatly needed to investigate the activities of the vectors and virus circulation.

The early dedication of emergence and infectious diseases require the presence and intervention of multidisciplinary teams of well trained scientific staff e.g epidemiologists, entomologists, virologists, climatologist, economists, etc, which should be maintained as a national resource.

General Conclusion

The outbreak of RVF in 2000-2001 in Saudi Arabia and Yemen opened a new era in the epidemiological history of the disease. It indicated that the virus has the ability to cross continents and affect new areas in the world.

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The impact –socio-economic as well as on human health of the RVF was dramatic. The diagnosis and confirmation was late despite a very effective and quick reaction from the veterinary services, the ministry of health, and the related authorities as well as international organizations like FAO, OIE, NAMUR3 Cairo and AEIA.

If the consequences were severe it also had benefits among which drawing the attention of the decision makers on the importance of this zoonotic disease with its impact on human health and national economy; and strengthening the cooperation between veterinary and human doctors that now work more together to control and prevent epidemics of RVF but also of other zoonotic diseases. The evaluation of the total impact of the outbreak has a great importance for the planning of a strategy to control and prevent the future disease occurrence but is difficult as it affected all sectors of life. However when RVF affects a country, the impact is such that years are needed to compensate the livestock production losses encountered, to regain the consumer's confidence and to compensate for human injuries when it is possible. This huge impact on the national but more broadly on the regional and international economy is well illustrated by the review of the record of the outbreaks in different regions in Africa and the Middle East.

The risk of the re-introduction and re-emergence of RVFV to Yemen was shown to be high.

Rift Valley Fever is one of the the most dangerous zoonotic disease in the world threatening human health and especially the health of people who live in close contact with animals. The threat is real, while there is no licensed and safe vaccine available for humans. Outbreaks can lead to loss of precious human lives and can also result in a ban of the export of livestock for three years according the OIE and WTO rules. This results in a very heavy socio- economic impact on the region in particular on the Horn of Africa as animal trade is in the centre of the livelihood of the population and in particular of the poor pastoralist communities. For this reason, the control and prevention of RVF has a great importance.

Moreover, in the last decade the veterinary services and quarantine facilities improved to some extent following the greater attention being given by international organizations like OIE, FAO, IAEA and USAID. However, it is not sufficient in the view of the high livestock population in the East of Africa and the size of the trade with the Middle East as well as the fast development of world transport and the resulting greater contacts between people, between animals and between people and animals. A single animal case of RVF is sufficient, in the presence of the favorable vectors, to introduce the virus and set off the expansion of the disease in any new area in the world, as demonstrated by the dramatic spread of West Nile in USA or bluetongue in northern Europe.

The establishment of regional surveillance networks along with the use and finetuning of the predictive model established in May 2009 by the OIE regional office in collaboration with FAO, OIE, WHO, and NASA, can be a good strategy for controlling RVF. It could also serve as a good basis to show the benefits of the "One Health" approach for disease control that could then be extended to the prevention and eradication of Rift Valley Fever and other trans-boundary animal disease.

The results of this study will be communicated to the General Directorate of Animal Health & Veterinary Quarantine, and to the Ministry of Agriculture and Irrigation, Sana'a, Yemen. It illustrates the need for research on the vectors and the socio-economic impact of the disease as well as the risk of the re-introduction of RVF into the country.

Summary

From 1930 to 2000 Rift Valley Fever (RVF) was limited to the African continent. RVF is vector borne disease caused by a virus of the genus Phlebovirus, member of the Bunyaviridae family. The main vectors for transmission are from *Aedes* and *Culex* genera. In September 2000 it was reported for the first time out of Africa, affecting Yemen and Saudi Arabia. This epidemic opened a new era in the history of RVF. It proved that the virus had the capacity to affect new zones, and different eco-systems.. Although difficult to evaluate precisely its socio-economic impact was considered to be the heaviest in the modern history of Yemen animal diseases even when compared to the rinderpest outbreak that the country encountered in the seventies because of its zoonotic characteristic. The outbreak lifted many hypothesis related to its introduction and to the factors associated with the outbreak. To answer to these hypotheses it was of great importance to study and investigate all the factors associated with the outbreak. Thus after estimating the socio-economic impact of the disease in the world and more specifically in Yemen we studied the descriptive epidemiology of RVF in the first and most affected zone of the outbreak of 2000-2001 (Tihama Wadi Mawr) and then we analysed the socio-economic and environmental factors associated to the outbreak, to finish with the risk assessment of the re-introduction of RVFV from the Horn of Africa through legal animals trade.

The descriptive study showed that at the national level 90% of the RVF cases were in the plain of Tihama coast, Hodiedah, Hajjah and Sadah governorates, the majority of the villages being located around the main canals of Wadi Mawr at an altitude < 300 m.

Environmental as well as socio-economic factors likely to play a role in RVF transmission in Yemen were highlighted with the study of the period 1997-2007 in the country. As in previous RVF outbreaks in neighbouring countries in the Horn of Africa, the year 2000 presented above-normal vegetation index values, which reflected important precipitations, for both rainy seasons (the first occurring between March and May; the second between July and October). These environmental conditions favourable to the vectors populations were found concomitant with a late starting date of Eid-al Kabeer celebration (March) in 2000, related to high hosts (cattle, sheep and goats) densities. According to these criteria, 2000 was considered as an atypical year.

Yemeni Veterinary Services did not declare any RVF outbreak since 2000. Thus, we assumed Yemen free of the disease when assessing the risk of introduction of RVF into Yemen via the legal trade of small ruminants from the Horn of Africa (Kenya, Somalia,

Djibouti, and Ethiopia). After precisely describing the routes and volume of trade from the Horn of Africa to Yemen, the pathway and different scenarios for introduction were developed following the OIE risk assessment method. The overall probability of introduction was assessed very low to medium depending on the period of the year and most likely to occur via ovine males exported during festival periods that change depending of the year considered.

The socio-economic impact although difficult to estimate was shown to be dramatic as RVF affects all the chain of life in particular of those associated to livestock and animal products trade.

Despite the dramatic impact of the outbreak of RVF in 2000 it had the advantage to draw the attention of decision makers, of international organizations and of local veterinary services on the importance of livestock diseases and their possible effects on human health and national economies. Veterinary education also improved significantly in Yemen. It enhanced the epidemiologist’s skills, disease surveillance in general and the cooperation between human health care people and veterinary services. A national P3 laboratory should also soon open with the help of the IAEA and the FAO and Al-Mukkah quarantine could be modernized and extended in the near future.

Regional collaboration and improvement of knowledge on animal trade but also field studies related to the disease and its entomological features are seen as compulsory to hope improving the prevention and control of RVF.But the best way and strategy for prevention of Rift Valley Fever in Yemen as well as in the world is to develop more efficient surveillance and control tools to implement coordinated regional monitoring and control programmes.

Résumé

De 1930 à 2000, la Fièvre de la Vallée du Rift (RVF) était une maladie essentiellement africaine.

C'est une maladie vectorielle causée par un virus du genre Phlebovirus de la famille des Bunyaviridae. Les principaux vecteurs sont les *Aedes* et les *Culex*. En Septembre 2000, des cas furent rapportés pour la première fois hors du continent africain touchant le Yémen et l'Arabie Saoudite. Cette épidémie ouvrit une nouvelle ére dans l'histoire de la RVF. Elle prouva la capacité du virus à infecter des zones nouvelles, et des écosystèmes differents.

S'il est difficile d'évaluer précisement son impact socio-economique, il fut considéré comme le plus lourd de l'histoire moderne des maladies animales au Yémen même comparé à celui de la peste bovine dans les années 70 à cause de son caractère zoonotique.

Plusieurs hypothèses furent avancées concernant son introduction et les facteurs socio-économiques associés aux foyers. Pour répondre à ces hypothèses, il était important d'étudier et de rechercher tous les facteurs associés aux foyers. Ainsi après avoir estimé l'impact socio-economique de la maladie dans le monde et plus particulièrement au Yemen, l'on s'intéréssa à l'épidémiologie descriptive de la RVF dans les premières zones touchées mais aussi les plus affectées lors des foyers de 2000-2001 (Tihama Wadi Mawr) Puis l'on analysa les facteurs socio-économiques et environmentaux associés aux foyers pour finir avec l'évaluation de risque de la réintroduction du RVFV à partir du commerce légal d'animaux de la Corne d'Afrique.

L'étude descriptive montre qu'au niveau national, en 2000-2001 environ 90 % des cas étaient dans la plaine de la côte de Tihama, Hodiedah, Hajjah et Sadah, la plupart des villages étant localisés autour des canaux principaux de Wadi Mawar à une altitude infereure à 300 Mètres (m). Les facteurs environmentaux et socio-économiques susceptibles d'avoir un rôle dans la transmission de la RVF au Yémen furent soulignés avec l'étude de la période 1997-2007 dans le pays. Comme dans les foyers précédents de RVF dans les pays voisins de la Corne de l'Afrique, l'année 2000 présentait des valeurs anormalement élevées d'index normal de végétation refletant d'importantes précipitations lors des deux saisons des pluies (la première entre mars et mai, la seconde entre juillet et octobre). Ces conditions environmentales favorables aux populations de vecteurs apparurent concommitantes avec une date tardive de début des festivités de l'Eid-al Kabeer en (mars) 2000 entraînant une densité importante de populations hôtes (bovins, moutons, chèvres). Considérant ces facteurs l'année 2000 fut considérée comme une année atypique.

Les services vétérinaires yéménites n'ont pas déclaré de foyers de RVF depuis 2000. Ainsi on fit l'hypothèse que le Yémen n'était plus infecté et nous nous sommes intéressés au risque de ré-introduction de la RVF au Yémen via le commerce légal de petits ruminants depuis la Corne de l'Afrique (Kenya, Somalie, Djibouti et Ethiopie). Après avoir précisemment décrit les routes et volumes d'échanges depuis la Corne de l'Afrique jusqu'au Yémen, les chemins événementiels et différents scénarios d'introduction furent développés en suivant la méthode de l'OIE. Une matrice de combinaison des probabilités incluant quatre niveaux (très bas, bas, modéré, élevé) fut construite et utilisée pour combiner les probabilités de réalisation des évènements. La probabilité globale d'introduction fut est très basse à modérée . Elle est liée à l'introduction d'ovins males exportés pendant les périodes de fêtes dont l'occurrence change en fonction de l'année considérée.

Si l'impact socio-économique de la RVF est difficile à évaluer, il est pourtant dramatique en atteignant tous les maillons du réseau de ceux dont la vie s'organise autour du bétail et de son commerce ou du commerce de ses produits. En dépit de l'impact dramatique des foyers de RVF en 2000, la maladie a attiré l'attention de décideurs, d'organisations internationales et des services vétérinaires locaux sur l'importance des maladies de bétail et leurs effets possibles sur la santé humaine et les économies nationales. L'éducation vétérinaire s'est aussi améliorée de façon significative au Yémen. La qualification des épidémiologistes et la surveillance des maladies en général s'en sont trouvées meilleures, ainsi que la coopération entre les services médicaux humains et les services vétérinaires. Un laboratoire national P3 devrait voir le jour prochainement avec l'aide de l'IAEA (International Atomic Energy Agency) et de la FAO (Food and Agriculture Organization). La modernisation et l'extension de la quarantaine Al-Mukkah, est aussi prévue dans un avenir proche.

La collaboration régionale, l'amélioration de la connaissance du commerce du bétail mais aussi des études de terrain relatives à la maladie et à ses caractéristiques épidémiologiques sont indispensables pour espérer améliorer la prévention et le contrôle de la RVF. Mais la meilleures stragtègie pour la prévention de la fièvre de la vallée de Rift au Yemen comme dans le monde est de developper une surveillance efficace et mettre au point des outils de contrôle adpatés.

References

Abd El-Rahim, I., U. El-Hakim, et al. (1999). "An epizootic of Rift Valley fever in Egypt in 1997." Rev Sci Tech Off Int Epi. **18**(3): 741-748.

Abdo-Salem, S., G. Gerbier, et al. (2006). "Descriptive and spatial epidemiology of Rift valley fever outbreak in Yemen 2000-2001." Annals of the New York Academy of Sciences **1081**: 240-242.

Ahmad, K. (2000). "More deaths from Rift Valley fever in Saudi Arabia and Yemen." Lancet **356**(9239): 1422.

Ahrens, J. (1998). Cessation of livestock exports severely affects the pastoralist economy of Somali Region. Addis-Ababa UNDP Emergencies Unit for Ethiopia (EUE) 5.

Akakpo, A., J. Saluzzo, et al. (1991). "Epidemiology of Rift Valley fever in west Africa. 1. Serological investigation of small ruminants in Niger." Bull Soc Pathol Exot **84**(3): 217-224.

Aklilu, Y. (2002). "An Audit of the Livestock Marketing Status in Kenya, Ethiopiaand Sudan Animal Resources, . ." PAPCE,OAU Community-Based Animal Health and Participatory Epidemiology Unit. **II**(Nairobi Kenya): 35.

Al Qadasi, M. (2002). Rift Valley fever outbreak in Yemen, September 2000 to February 2001. 27 th World Veterinary Congress, Tunisia, Tunis,.

Al Qadasi, M. (2009). Rift valley Fever outbreak in Yemen Sep2000/March 2001 and surveillance follow up. Rift Valley Fever Workshop: An integrated approach to controlling Rift Valley Fever (RVF) in Africa and the Middle East, Cairo, Egypt.

Alabsi, A. (2006, May 2006). "Yemen." J.M. Suttie and S.G. Reynold. Retrieved 07/10/2008, from http://www.fao.org/ag/AGP/AGPC/doc/Counprof/Yemen/yemen.htm,.

Alary, V. (2006). Etude du commerce régional du bétail et des produits animaux en Afrique de l’Ouest (zone ECOWAS) et Afrique de l’Est (zone IGAD). Montpellier, France, CIRAD.

Alqadasi.M (2009). Rift Valley Fever outbreak in Yemen Sep 2000/March 2001 and surveillance follow up. An integrated approach to controlling Rift Valley Fever in Africa and Middle East.. Cairo, Egypt.USAID.

Anonyme (2000). "Outbreak of Rift Valley fever, Yemen, August-October 2000." Wkly Epidemiol Rec **75**(48): 392-5.

Anonyme (2000). "Rift Valley fever, Saudi Arabia, August-October 2000." Wkly Epidemiol Rec **75**(46): 370-1.

Anyamba, A., J. Chretien, et al. (2009). "Prediction of a Rift Valley fever outbreak." Proceedings of the National Academy of Sciences of the United States of America **106(3)**: 955-9.

Anyamba, A., J. P. Chretien, et al. (2006). "Rift Valley fever potential, Arabian Peninsula." Emerging Infectious Diseases **12**(3): 518-520.

Anyamba, A., J. P. Chretien, et al. (2007). "Forecasting the temporal and spatial distribution of a rift valley fever outbreak in east Africa: 2006-2007." American Journal of Tropical Medicine and Hygiene **77**(5): 282-283.

Anyamba, A., J. P. Chretien, et al. (2006). "Developing global climate anomalies suggest potential disease risks for 2006-2007." International Journal of Health Geographics **5**: 60.

Anyamba, A., K. J. Linthicum, et al. (2001). "Climate-disease connections: Rift Valley Fever in Kenya." Cad Saude Publica **17 Suppl**: 133-40.

ARD (2006). Livestock movement and trads study for the Yemen agricultural support program., ARD,Inc p.o Box 1397 Burlington 2006 VT05402**:** 51.

AREA (1997). Agricultural Research and Extension Authority Agro-Climatic Resources of Yemen. Part 1. Dhamar

Arthur, R. R., M. S. el-Sharkawy, et al. (1993). "Recurrence of Rift Valley fever in Egypt." Lancet **342**(8880): 1149-1150.

Authority, T. D. (1987). Wadi development for agriculture in Yemen Arab Republic. Proceedings of the Subregional Expert Consultation on Wadi Development for Agriculture in the Natural Yemen, Aden, Yemen

Balkhy, H. and Z. Memish (2003). "Rift Valley fever: an uninvited zoonosis in the Arabian peninsula." Int J Antimicrob Agents **21**(2): 153-7.

Barnard, B. (1979). "Rift Valley fever vaccine--antibody and immune response in cattle to a live and an inactivated vaccine." J S Afr Vet Assoc **50**(3): 155-7.

Barnard, B. and M. Botha (1977). "An inactivated Rift Valley fever vaccine." J S Afr Vet Assoc **48**(1): 45-48.

Beaty, B. and W. Marquardt (1996). The biology of disease vectors. Niwot, University Press of Colorado.
Bird, B., C. Albarino, et al. (2008). "Rift valley fever virus lacking the NSs and NSm genes is highly attenuated, confers protective immunity from virulent virus challenge, and allows for differential identification of infected and vaccinated animals." J Virol **82**(6): 2681-91.
Bird, B. H., M. L. Khristova, et al. (2007). "Complete genome analysis of 33 ecologically and biologically diverse Rift Valley fever virus strains reveals widespread virus movement and low genetic diversity due to recent common ancestry." J Virol **81**(6): 2805-16.
Bird, B. H., T. G. Ksiazek, et al. (2009). "Rift Valley fever virus." J Am Vet Med Assoc **234**(7): 883-93.
Boiro, I., O. Konstaninov, et al. (1987). "Isolation of Rift Valley fever virus from bats in the Republic of Guinea." Bull Soc Pathol Exot Filiales **80**(1): 62-67.
Botros, B., A. Omar, et al. (2006). "Adverse response of non-indigenous cattle of European breeds to live attenuated Smithburn Rift Valley fever vaccine. ." *J Med Virol* **78:**: 787-791.
Bouloy, M. and R. Flick (2009). "Reverse genetics technology for Rift Valley fever virus: Current and future applications for the development of therapeutics and vaccines." Antiviral Research **84**(2): 101-118.
Breiman, R., M. Njenga, et al. (2008). "Lessons from the 2006–2007 Rift Valley fever outbreak in East Africa: implications for prevention of emerging infectious diseases." Future medicine **3 (5)**: 411-417.
Brown, J., J. Dominik, et al. (1981). "Respiratory infectivity of a recently isolated Egyptian strain of Rift Valley fever virus." Infect Immun **33**(3): 848-53.
Caplen, H., C. Peters, et al. (1985). "Mutagen-directed attenuation of Rift Valley fever virus as a method for vaccine development." J Gen Virol **66**(Pt 10)): 2271-7.
CDC (1998). "Rift Valley Fever--East Africa, 1997-1998." MMWR Morb Mortal Wkly Rep **47**(13): 261-4.
CDC (2000). "Outbreak of Rift Valley fever, Yemen, August-October 2000." Weekly Epidemiological Record **75**(48): 392-395.
CDC (2000). "Update: Outbreak of Rift Valley fever- Saudi Arabia-August-October, 2000." Morbidity and Mortality Weekly Report **49**: 905-908.
CDC (2000b). "Update : outbreak of Rift Valley fever- Saudi Arabia, August-November, 2000." Morb Mortal Wkly Rep **49**: 982-985.
CDC (2007). "Rift Valley Fever outbreak-Kenya, November 2006-January 2007." **MMWR Morb Mortal Wkly Rep 54(04)**(02/02/2007): 73-76.
CDC. (2007, 13/11/2008). "Rift Valley Fever Outbreak Kenya, November 2006--January 2007." 2008, from http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5604a3.htm.
Chevalier, V., S. Delarocque, et al. (2004). "Epidemiological processes involved in the emergence of vector-borne diseases: West Nile fever, Rift Valley fever, Japanese encephalitis and Crimean-Congo haemorrhagic fever." Rev .Sci.Tech. **23**(2): 535-555.
Chevalier, V., R. Lancelot, et al. (2005). "Incidence of Rift Valley fever in small ruminants in the Ferlo pastoral system (Senegal) during the 2003 rainy season." Emerg Inf Dis **11**(11): 1693-1700.
Chevalier, V., V. Martin, et al. (2008). Combating and predicting Rift Valley fever outbreaks: a scientific and geopolitical challenge for the future. Emerging infections 8. W. M. Scheld, S. M. Hammer and J. M. Hughes. Washington, ASM Press**:** 189-212.
Chevalier, V., B. Mondet, et al. (2004). "Exposure of sheep to mosquito bites: possible consequences for the transmission risk of Rift Valley fever in Senegal." Med Vet Entomol **18**: 247-255.
Chevalier, V., M. Pépin, et al. (2010). "Rift Valley fever - a threat for Europe?" Euro Surveill **15(10) 19506**.
Christe, G. (1969). "Rift Valley Fever ." Rhodesia Science News **3**: 238-240.
Clements, A., D. Pfeiffer, et al. (2007). "A Rift Valley fever atlas for Africa." Preventive Veterinary Medicine **82**(1-2): 72-82.
Coackley, W., A. Pini, et al. (1967). "Experimental infection of cattle with pantropic Rift Valley fever virus." Res Vet Sci **8**(4): 399-405.
Coetzer, J. (1977). "The pathology of Rift Valley fever. I. Lesions occurring in natural cases in new-born lambs." Onderstepoort J Vet Res **44**(4): 205-11.
Coetzer, J. and B. Barnard (1977). "Hydrops amnii in sheep associated with hydranencephaly and arthrogryposis with wesselsbron disease and rift valley fever viruses as aetiological agents." Onderstepoort J Vet Res **44**(2): 119-26.

Coetzer, J. and K. Ishak (1982). "Sequential development of the liver lesions in new-born lambs infected with Rift Valley fever virus. I. Macroscopic and microscopic pathology." Onderstepoort J Vet Res **49**(2): 103-8.

CSO (1999). Results of Labour Force Survey in Yemen, Central Statistics Organisation. Sana'a.

Daubney, R., J. Hudson, et al. (1931). "Enzootic hepatitis or Rift Valley fever. An undescribed virus disease of sheep cattle and man from East Africa." The Journal of Pathology and Bacteriology **34**(4): 545-579.

Daubney, R., J. Hudson, et al. (1931). "Enzootic hepatitis or Rift Valley fever: an undescribed disease of sheep, cattle and man from east Africa." Journal of Pathology and Bacteriology **89**: 545-579.

Davenport, M. L. and S. E. Nicholson (1993). "On the Relation between Rainfall and the Normalized Difference Vegetation Index for Diverse Vegetation Types in East-Africa." International Journal of Remote Sensing **14**(12): 2369-2389.

Davies, F. (1975). "Observations on the epidemiology of Rift Valley fever in Kenya." J Hyg **75**(2): 219-230.

Davies, F. (2000). Epizootic Rift Valley Fever in the Yemen Republic the year 2000. Roma, FAO**:** 24.

Davies, F. (2010). "The Historical and Recent Impact of Rift Valley Fever in Africa." The American Journal of Tropical Medicine and Hygiene **83**(2 Suppl): 73.

Davies, F. and R. Highton (1980). "Possible vectors of Rift Valley fever in Kenya." Trans Roy Soc Trop Med Hyg **74**(6): 815-816.

Davies, F. and L. Karstad (1981). "Experimental infection of the African buffalo with the virus of Rift Valley fever." Trop Anim Health Prod **13**(4): 185-188.

Davies, F., K. Linthicum, et al. (1985). "Rainfall and epizootic Rift Valley fever." Bull World Health Organ **63**(5): 941-3.

Davies, F. G. (2006). "Risk of a rift valley fever epidemic at the haj in Mecca, Saudi Arabia." Rev Sci Tech **25**(1): 137-47.

Davies, G. and V. Martin (2003). Recognizing Rift Valley Fever. Roma, FAO,Animal Health Manual No 17.

Davies, G. and M. Nunn (1998). Risk of Rift Valley Fever From Livestock Imported into the Kingdom of Saudi Arabia from the Horn of Africa. FAO. Rome FAO**:** 17.

Davies, G. F. (2000). Rift Valley Fever in Yemen. Roma, Food and Agriculture Organization.

Davis, F. and V. Martin (2006). "Recognizing Rift Valley fever." Vet Ital **42**: 31-53.

Davis, F. G. (2006). "Risk of Rift Valley fever epidemic at the Haj in Mecca, Saudi Arabia." Rev Sci Tech Off Int Epi **25**(1): 137-147.

De Deken, R., V. Martin, et al. (2007). "An outbreak of East Coast Fever on the Comoros: A consequence of the import of immunised cattle from Tanzania?" Veterinary Parasitology **143**(3-4): 245-253.

De La Rocque, S. and P. Formenty (2009). Rift Valley Fever ,Epidemiology,Ecology, Predication and early warning. WP2 Arbozoonet, Montpellier France.

Digoutte, J. P. and C. J. Peters (1989). "General aspects of the 1987 Rift Valley fever epidemic in Mauritania." Res Virol **140**(1): 27-30.

Diop, G., Y. Thiongane, et al. (2000). "The potential role of rodents in the enzootic cycle of Rift Valley fever virus in Senegal." Microbes and infection **2**: 343-346.

Dungu, B., I. Louw, et al. (2010). "Evaluation of the efficacy and safety of the Rift Valley Fever Clone 13 vaccine in sheep." Vaccine **10496**: 7.

Eddy, G. and C. Peters (1980). "The extended horizons of Rift Valley fever: current and projected immunogens." Prog Clin Biol Res **47**: 179-91.

Eisa, M. and H. Obeid (1977 b). "Rift Valley fever in the Sudan. II. Isolation and identification of the virus from a recent epizootic in Kosti District, 1973." Bull Animal Health Prod Africa **24**: 349-355.

EMPRES, F. (2007, 13/11/2008). "Rift Valley Fever could spread with movement of animals from East Africa." Retrieved 10/09/2009, from http://www.fao.org/docs/eims/upload/236966/EW_africa_dec07_rvf.pdf.

Erasmus, B. and J. Coetze (1981). "The symptomatology and pathology of Rift Valley fever in domestic animals." Contrib. Epidemiol. Biostat **3**: 77-82.

Evans, A., F. Gakyua, et al. (2008). "Prevalence of antibodies against Rift Valley Fever virus in Kenya wildlife " Epidemiol Infect **136**: 261-269.

Fakhfakha, E., A. Ghrama, et al. (2010). "First serological investigation of peste-des-petits-ruminants and Rift Valley fever in Tunisia " The Veterinary Journal.

FAO. "Rift Valley Fever." EMPRES Transboundary Animal Diseases Bulletin. Retrieved 10/03/2009, from http://www.fao.org/docrep/x3444e/x3444e01.htm.

FAO (1997). Underlying Causes of Desertification, . Roma.

Farquharson, F., D. Plinston, et al. (1996). "Rainfall and runoff in Yemen." Hydmlegical Sciences - Journal- des Sciences Hjdmlogiques. **41 (5)** 797-811.

FEWS Net (2007). Brief Report on the Impact of Rift Valley Fever in the Horn of Africa Nairobi, Regional Food security and Nutrition Working Group.**:** 3.

FEWS.Net. (2000). "Rift Valley fever threatens livelihoods in the Horn of Africa." Retrieved 7/12/2009, from http://www.fao.org/docrep/003/y0482E/y0482e04.htm.

Findlay, G. M. and E. M. Howard (1951). "Notes on Rift Valley fever." Arch Gesamte Virusforsch **4**(4): 411-23.

Fleming, D. E., N. Hammadi, et al. (2008). Livestock movement and trade study for the Yemen agricultural support Burlington, ARD, Inc.

Flick, R. and M. Bouloy (2005). "Rift Valley fever virus." Current Molecular Medicine **5**(8): 827-834.

Fontenille, D., M. Traore-Lamizana, et al. (1998). "New vectors of Rift Valley fever in West Africa." Emerg Infect Dis **4**(2): 289-293.

Fontenille, D., M. Traore-Lamizana, et al. (1994). "First isolations of arboviruses from phlebotomine sand flies in West Africa." Am J Trop Med Hyg **50**(5): 570-4.

Garcia, S., J. Crance, et al. (2001). "Quantitative real-time PCR detection of rift valley Fever virus and its application to evaluation of antiviral compounds." J Clin Microbiol **39**(12): 4456-61.

Gear, J. H. (1977). "Haemorrhagic fevers of Africa: an account of two recent outbreaks." J S Afr Vet Assoc **48**(1): 5-8.

Georges, A. J., S. A. Wahid, et al. (1983). "Serological evidence of endemic Zinga virus and Rift Valley fever virus in Central African Republic." Lancet **1**(8337): 1338.

Gerdes, G. (2004). "Rift Valley fever." Revue Scientifique et technique de l'Office International des Epizooties **23**(2): 613-623.

Global Warming and climate. (2010). "The causes of global warming and climate change!" Retrieved 24/02/2010, from http://www.global-warming-and-the-climate.com/.

Globalfund. (2006). "Yemen and Malara:Scaling up Malarai Prevention " Retrieved 13/01/2010, from http://www.theglobalfund.org/fr/savinglives/yemen/malaria1/?part=part2.

Gonzalez, J., J. McCormick, et al. (1983). "Les fièvres hémorragiques africaines d'origine virale. Contribution à leur étude en République Centrafricaine." Cahiers de l'ORSTOM. Série Entomologie Médicale et Parasitologie **21**: 119-130.

Grgacic, E. and D. Anderson (2006). "Virus-like particles: Passport to immune recognition." Methods **40**: 60-65.

Haas, E. M., E. Bartholome, et al. (2009). "Time series analysis of optical remote sensing data for the mapping of temporary surface water bodies in sub-Saharan western Africa." Journal of Hydrology **370**(1-4): 52-63.

Habjan, M., A. Pichlmair, et al. (2009). "NSs protein of rift valley fever virus induces the specific degradation of the double-stranded RNA-dependent protein kinase." Virol **83(9)**: 4365-4375.

Handlos, M. (2009). Summary assessment of the estimated costs of past disease outbreaks in the country. Sana'a & Vientiane ICON&JVL Consulting**:** 34.

Harrington, D., H. Lupton, et al. (1980). "Evaluation of a formalin-inactivated Rift Valley fever vaccine in sheep." Am J Vet Res **41**(10): 1559-64.

Heise, M., A. Whitmore, et al. (2009). "An alphavirus replicon-derived candidate vaccine against Rift Valley fever virus." Epidemiol Infect **137 (9)**: 1309--1318.

Holleman, C. (2002). The Socio-economic Implication of the Livestock Ban in Somaliland. TASK Order 2. Nairobi, USAID**:** 62.

Hoogstraal, H., J. Meegan, et al. (1979). "The Rift Valley fever epizootic in Egypt 1977-78. 2. Ecological and entomological studies." Trans Roy Soc Trop Med Hyg **73**(6): 624-629.

Ikegamia, T. and S. Makino (2009). "Rift Valley fever vaccines." Vaccine. **27(4,5)**(2009): D69-D72.

ILRI /FAO (2009). Decision-support tool for prevention and control of Rift Valley fever epizootics in the Greater Horn of Africa. A. A. ILRI Publication Unit, Ethiopia. Nairobi, ILRI,USAID, FAO. **7:** 28.

Jost, C. C., S. Nzietchueng, et al. (2010). "Epidemiological assessment of the Rift Valley fever outbreak in Kenya and Tanzania in 2006 and 2007." Am J Trop Med Hyg **83**(2 Suppl): 65-72.

Jouan, A., F. Adam, et al. (1990). "Epidemic of Rift Valley fever in the Islamic republic of Mauritania. Geographic and ecological data." Bull Soc Pathol Exot **83**(5): 611-20.

Jouan, A., B. Le Guenno, et al. (1988). "An RVF epidemic in southern Mauritania." Ann Inst Pasteur Virol **139**(3): 307-308.

Jupp, P., A. Grobbelaar, et al. (2000). "Experimental detection of Rift Valley fever virus by reverse transcription-polymerase chain reaction assay in large samples of mosquitoes." Journal of medical entomology. **37(3)** (0022-2585): 467-471.

Jupp, P., A. Kemp, et al. (2002). "The 2000 epidemic of Rift Valley fever in Saudi Arabia: mosquito vector studies." Medical and veterinary entomology **16**(3): 245-252.

Kanipe, D. and P. Howley (2009). Fields Virology C.H.I.P.S.

Kark, J., Y. Aynor, et al. (1982). "A rift Valley fever vaccine trial. I. Side effects and serologic response over a six-month follow-up." Am J Epidemiol **116**(5): 808-20.

Kokernot, R. and E. Szlamp (1965 b). "Survey for antibodies against arthropod-borne viruses in the sera of indigenous residents of the caprivi strip and bechuanaland protectorate* 1." Transactions of the Royal Society of Tropical Medicine and Hygiene **59**(5): 553-562.

Kortekaas, J., A. Dekker, et al. (2010). "Intramuscular inoculation of calves with an experimental Newcastle disease virus-based vector vaccine elicits neutralizing antibodies against Rift Valley fever virus." Vaccine. **28(11)**(2010 Mar 8): 2271-6.

LaBeaud, A., E. Muchiri, et al. (2008). "Interepidemic Rift Valley Fever Virus Seropositivity, Northeastern Kenya." Emerging Infectious Diseases **14(8)**(August 2008): 1240-6.

Le Roux, C., T. Kubo, et al. (2009). "Development and Evaluation of a Real-Time Reverse Transcription-Loop-Mediated Isothermal Amplification Assay for Rapid Detection of Rift Valley FeverVirus in Clinical Specimens." MICROBIOLOGY, **47(3)**: 645-651.

Lefèvre, P., J. Blancou, et al. (2003). Principales maladies infectieuses et parasitaires du bétail. Europe et régions chaudes. Généralités. Maladies virales. Londres. Paris. New york.

Linthicum, K., A. Anyamba, et al. (1999). "Climate and satellite indicators to forecast Rift Valley fever epidemics in Kenya." Science **285**(5426): 397-400.

Linthicum, K., H. Kaburia, et al. (1985). "A blood meal analysis of engorged mosquitoes found in Rift Valley fever epizootics area in Kenya." J Am Mosq Control Assoc **1**(1): 93-5.

Linthicum, K. J., F. G. Davies, et al. (1985). "Rift Valley fever virus (family *Bunyaviridae*, genus *Phlebovirus*). Isolations from *Diptera* collected during an inter-epizootic period in Kenya." J Hyg **95**(1): 197-209.

Liu, L., C. Celma, et al. (2008). "Rift Valley fever virus structural proteins: expression, characterization and assembly of recombinant proteins." Virol **5:82**.

Lorenzo, G., R. Martin-Folgar, et al. (2010). "Protection against lethal Rift Valley fever virus (RVFV) infection in transgenic IFNAR(-/-) mice induced by different DNA vaccination regimens." Vaccine **28**(17): 2937-44.

Madani, T. A., Y. Y. Al-Mazrou, et al. (2003). "Rift Valley fever epidemic in Saudi Arabia: epidemiological, clinical, and laboratory characteristics." Clinical Infectious Diseases **37**(8): 1084-92.

Marrama, L., A. Spiegel, et al. (2005). "Domestic transmission of Rift Valley fever virus in Diawara (Senegal) in 1998." Microbes Infect **7**: 682-687.

Martin, V., V. Chevalier, et al. (2008). "The impact of climate change on the epidemiology and control of Rift Valley fever." PubMed. **27(2)**: 413-26.

McIntosh, B. and P. Jupp (1981). "Epidemiological aspects of Rift Valley fever in South Africa with reference to vectors." Contrib Epidemio Biostat **3**: 92-99.

McIntosh, B., D. Russell, et al. (1980). "Rift Valley fever in humans in South Africa." S Afr Med J **58**(20): 803-806.

McIntosh, B. M., P. G. Jupp, et al. (1980). "Vector studies on Rift Valley Fever virus in South Africa." S Afr Med J **58**(3): 127-132.

McMichael, A., A. Haines, et al. (1996). Climate Change and Human Health. Geneva, WHO.

Medina, D. and S. Tempias (2008). Rift Valley Fever risk for small ruminants in Somalia :Towards the development of an early warning system for the ruminanats &humans. Nairobi Kenya., SAHSP,**:** 32.

Meegan, J. (1981). "Rift Valley Fever in Eygpt:An overview of the epizootics in 1977 and 1978." Contrib.Epidemiol.Biostat.(3): 100-113.

Meegan, J. and C. Bailey (1988). Rift Valley fever. In Arboviruses Epidemiology and Ecology. Boca Raton, FL, C.R.C Press.

Meegan, J., C. Baily, et al. (1989). " Rift Valley Fever: the arbovirus epidemiology and ecology " (T.P. Monath, ed.) **4**: 51-76.

Meegan, J. M., M. I. Moussa, et al. (1978). "Ecological and epidemiological studies of Rift Valley fever in Egypt." J Egypt Public Health Assoc **53**(3-4): 173-5.

Miller, B., M. Godsey, et al. (2002). "Isolation and genetic characterization of Rift Valley fever from *Aedes vexans arabiensis*, Kingdom of Saudi Arabia." Emerg Infect Dis **8**(12): 1492-1494.

Mondet, B., A. Diaïté, et al. (2005). "Rainfall patterns and population dynamics of *Aedes (Aedimorphus) vexans arabiensis* Patton, 1905 (*Diptera*, *Culicidae*), a potential vector of Rift Valley fever virus in Senegal." J Vector Ecology **30**(1): 102-110.
Morrill, J., L. Carpenter, et al. (1991). "Further evaluation of a mutagen-attenuated Rift Valley fever vaccine in sheep." Vaccine **9**(1): 35-41.
Morvan, J., J. Lesbordes, et al. (1992). "First fatal human case of Rift Valley fever in Madagascar." Trans R Soc Trop Med Hyg **86**(3): 320.
Morvan, J., P. Rollin, et al. (1992). "Duration of immunoglobulin M antibodies against Rift Valley fever virus in cattle after natural infection." Trans Roy Soc Trop Med Hyg **86**(6): 675.
Morvan, J., P. Rollin, et al. (1992). "Rift Valley fever in Madagascar in 1991. Sero-epidemiological studies in cattle." Rev Elev Med Vet Pays Trop. **45**(2): 121-7.
Moussa, M., K. Abdel-Wahab, et al. (1986). "Experimental infection and protection of lambs with a minute plaque variant of Rift Valley fever virus." Am J Trop Med Hyg **35**(3): 660-2.
Moutailler, S., G. Krida, et al. (2010). "Replication of Clone 13, a naturally attenuated avirulent isolate of Rift Valley fever virus, in Aedes and Culex mosquitoes." Vector Borne Zoonotic Dis **10**(7): 681-8.
Moutailler, S., G. Krida, et al. (2008). "Potential Vectors of Rift Valley Fever Virus in the Mediterranean Region." Vector-Borne and Zoonotic Diseases. **8(6)**: 749-754.
Muller, R., J. Saluzzo, et al. (1995). "Characterization of clone 13, a naturally attenuated avirulent isolate of Rift Valley fever virus, which is altered in the small segment." Am J Trop Med Hyg **53**(4): 405-411.
Mundel, B. and J. Gear (1951). "Rift Valley fever : occurence of human cases in Johannesburg." South. African. Medical. Journal **25**: 797-800.
Nabeth, P., Y. Kane, et al. (2001). "Rift Valley fever outbreak, Mauritania, 1998: seroepidemiologic, virologic, entomologic, and zoologic investigations." Emerg Infect Dis **7**(6): 1052-1054.
Näslund, J., N. Lagerqvist, et al. (2009). "Vaccination with virus-like particles protects mice from lethal infection of Rift Valley Fever Virus " Virol **385 (2)**: 408-415.
Naslund, J., N. Lagerqvist, et al. (2008). "Kinetics of Rift Valley Fever Virus in experimentally infected mice using quantitative real-time RT-PCR." Virol **151**: 277–282.
NICD South Africa. (2010). "Health workers guidlines on Rift Valley Fever (RVF)." from http://www.nicd.ac.za/outbreaks/rvf/rvf_outbreak.htm.
Nicholson, S. E. and T. J. Farrar (1994). "The Influence of Soil Type on the Relationships between Ndvi, Rainfall, and Soil-Moisture in Semiarid Botswana .1. Ndvi Response to Rainfall." Remote Sensing of Environment **50**(2): 107-120.
Niklasson, B. and T. Gargan (1985). "Enzyme-linked immunosorbent assay for detection of Rift Valley fever virus antigen in mosquitoes." Am J Trop Med Hyg **34**(2): 400-5.
Nzietchueng, S., B. Bernard, et al. (2007). Learning the lessons of Rift Valley fever:Improved Detection and Mitigation of Outbreak. IRLI workshop, Nairobi Kenya.
O'Malley, C. (1990). "*Aedes vexans* (Meigen): an old foe." Proc. N. J. Mosquito Control Assoc: 90-95.
Oelofsen, M. and E. Van der Ryst (1999). "Could bats act as reservoir hosts for Rift Valley fever virus?" Onderstepoort J Vet Res **66**(1): 51-54.
OIE (2000). Rift Valley Fever. OIE Manual Paris. **Chapter 2.1.8:** 144-154.
OIE. (2008). "Rift Valley Fever:Terrestrail Animals Health Code." Retrieved 16/06/2009, from http://www.oie.int/eng/Normes/mcode/en_chapitre_1.8.12.htm.
OIE. (2008). "Rift Valley FeverTerrestrial Manual 2.1.14,." Retrieved 23/06/2009, from http://www.oie.int/Eng/Normes/Mmanual/2008/pdf/2.01.14_RVF.pdf,.
Paul Reiter (2001). "Climate Change and Mosquito-Borne Disease." Environmental Health Perspectives **109**: 141-161.
Paweska, J., F. Brut, et al. (2005). "Validationof IgG-sandwish and IgM- capture ELISA for dedeication of antibody to Rift Valley Fever virus in Humans ." Virological Method **124**: 173-181.
Paweska, J., E. Mortimer, et al. (2005). "An inhibition enzyme-linked immunosorbent assay for the detection of antibody to Rift Valley fever virus in humans, domestic and wild ruminants." Virological Method **127**: 10-18.
Paweska, J., J. Van vuren, et al. (2008). "Recombinant nucleocapsid-based ELISA for detection of IgG antibody to Rift Valley fever virus in African buffalo." Veterinary Microbiology **127**(2008): 21-28.
Paweska, J., P. Van Vuren, et al. (2007). "Validation of an indirect ELISA based on a recombinant nucleocapsid protein of Rift Valley fever virus for the detection of IgG antibody in humans." Virological Methods **146**: 119-124

Peters, C. and G. Anderson (1981). "Pathogenesis of Rift Valley fever." Contrib Epidemio Biostat **3**: 31-41.
Peyrefitte, C., L. Boubis, et al. (2008). "Real-time reverse transcription loop-mediated isothermal amplification 1 for rapid 2 detection of Rift Valley fever virus." JCM.: 26.
Pittman, P., C. Liu, et al. (1999). "Immunogenicity of an inactivated Rift Valley fever vaccine in humans: a 12-year experience." Vaccine **18**(1-2): 181-9.
Pretorius, A., M. Oelofsen, et al. (1997). "Rift Valley fever virus: a seroepidemiologic study of small terrestrial vertebrates in South Africa." Am J Trop Med Hyg **57**(6): 693-698.
ProMed. (2006). "Rift Valley fever - Kenya (North Eastern Province)." Retrieved 6 Janvier 2007, 2006, from promed@promed.isid.harvard.edu.
ProMED. (2006). "Rift Valley Fever, East Africa (14) Tanzania,." International Society for Infectious Diseases Retrieved Tue 6 Feb 2007, 2007, from promed@promed.isid.harvard.edu.
ProMED. (2010). "Rift Valley Fever ,Animal- Botswana(02):(Gaborone)." Retrieved 09/07/2010, from http://gazettebw.com/index.php?option=com_content&view=article&id=6852:rift-valley-fever-hits-ramotswa&catid=18:headlines&Itemid=2.
ProMED. (2010). "Rift Valley fever - South Africa (11)." Retrieved 20/04/2010, from http://saweatherobserver.blogspot.com/2010/04/seven-from-e-cape-down-with-rift-valley.html.
Ringot.D, Durand.J.P, et al. (2004). "Rift Valley fever in Tchad." Emerg Infect Dis **10**(5): 945-947.
Rostal, M., A. Evans, et al. (2010). "Identification of potential vectors of and detection of antibodies against Rift Valley fever virus in livestock during interepizootic periods." American Journal of Veterinary Research **71**(5): 524-528.
Saeed, K. (2008). Rift Valley Fever control stratedgy for the flood affected Areas of Somalia. Nairobi, FAO**:** 38.
Sall, A., E. Macondo, et al. (2002). "Use of reverse transcriptase PCR in early diagnosis of Rift Valley fever." Clin Diagn Lab Immunol **9**(3): 713-5.
Sall, A., J. Thonnon, et al. (2001). "Single-tube and nested reverse transcriptase-polymerase chain reaction for detection of Rift Valley fever virus in human and animal sera." J Virol Methods **91**(1): 85-92.
Saluzzo, J., C. Chartier, et al. (1987). "Rift Valley fever in Western Africa." Rev Elev Med Vet Pays Trop **40**(3): 215-223.
Saluzzo, J., J. Digoutte, et al. (1987). "Focus of Rift Valley fever virus transmission in southern Mauritania." Lancet **1**(8531): 504.
Sang, R., E. Kioko, et al. (2010). "Rift Valley fever virus epidemic in Kenya, 2006/2007: the entomologic investigations." Am J Trop Med Hyg **83**(2 Suppl): 28-37.
Scott, G., W. Coackley, et al. (1963). "Rift Valley fever in camels." J Pathol Bacteriol **86**: 229-31.
Shih, T., C. Chou, et al. (2005). "Monte Carlo simulation of animal-product violations incurred by air passengers at an international airport in Taiwan." Preventive Veterinary Medicine **68 (2005)**: 115-122.
Shiil, M. (2008). Germany Donates Somali Refugees Centre in Yemen
Shimshony, A. and R. Barzilai (1983). "Rift Valley fever." Adv Vet Sci Comp Med **27**: 347-425.
Shimshony, A. and P. Economides (2006). "Disease prevention and preparedness for animal health emergencies in the Middle East,." Rev. sci. tech. Off. int. Epiz., **25 (1)**: 253-269.
Shoemaker, T., C. Boulianne, et al. (2002). "Genetic analysis of viruses associated with emergence of Rift Valley fever in Saudi Arabia and Yemen, 2000-2001." Emerging Infectious Diseases **8**(12): 1415-1420.
Shope, R., C. Peters, et al. (1982). "Rift valley fever: propagation and methods of control." Bull World Health Organ **60**(5): 703-9.
Sissoko, D., C. Giry, et al. (2009). "Rift Valley Fever, Mayotte, 2007-2008." Emerging Infectious Diseases • **15 (4)**: 568-70.
Smithburn, K., A. Mahaffy, et al. (1949). "Accidental Infections Among Laboratory Workers." The Journal of Immunology **62**: 213-227.
Soti, V., A. Tran, et al. (2009). "Assessing optical Earth observation systems for mapping and monitoring temporary ponds in arid areas " International Journal of Applied Earth Observation and Geoinformations **11**: 344-351.
Soumare, B., S. Tempia, et al. (2007). "Screening for Rift Valley fever infection in northern Somalia: A GIS based survey method to overcome the lack of sampling frame." Veterinary Microbiology **121**: 249-256.
Soumaré, B., E. Thys, et al. (2006). "Effects of livestock import bans imposed by Saudi Arabia on Somaliland for sanitary reasons related to Rift Valley fever " Outlook on Agriculture, Volume Number 1, March 2006 , pp. (6) **35(1)**: 19-24.

Spik, K., A. Shurtleff, et al. (2006). "Immunogenicity of combination DNA vaccines for Rift Valley fever virus, tick-borne encephalitis virus, Hantaan virus, and Crimean Congo hemorrhagic fever virus." Vaccine. **22;24 (21).** 4657-66.

Swanepoel, R. and J. Coetzer (1994). Rift Valley fever. Infectious diseases of livestock with special reference to South Africa. Cape Town, Oxford University Press. J.A.W. Coetzer, G. R. Thomson & R. C. Tustin. **I:** 688-717.

Swanepoel, R. and J. Coetzer (2004). Rift Valley Fever. Infectious diseases of livestock. J. C. a. R. Tustin, Oxford University Press**:** 1037-1070.

Swanepoel, R., J. Struthers, et al. (1986). "Comparative pathogenicity and antigenic cross-reactivity of Rift Valley fever and other African phleboviruses in sheep." J Hyg (Lond) **97**(2): 331-46.

Tahir, T. M. and A. A. Noman (2004). "Sediment problems of Irrigation Canals: Field studies to Assess the Changes in Canals profiles and Cross sections." Journal of Science & Technology **7**(2): 25-47.

Takehara, K., M. Min, et al. (1989). "Identification of mutations in the M RNA of a candidate vaccine strain of Rift Valley fever virus." Virology **169**(2): 452-7.

Thiongane, Y. and V. Martin (2003). Système sous-régional d'alerte et de contrôle de la Fièvre de la Vallée du Rift (FVR) en Afrique de l'Ouest. Bulletin d'information n°7. Dakar, ISRA-FAO**:** 15.

Tihama Development Authority (1986). Wadi development for Agriculture in Yemen Arab Republic, Tihama Development Authority Hodiedah Yemen 33.

Turell, M., D. Dohm, et al. (2008.). "Potential for North American mosquitoes to transmit Rift Valley fever virus. ." J. Am. Mosq. Control Assoc. **24**: 502-507.

Van Vuren, J., A. Potgieter, et al. (2007). "Preparation and evaluation of a recombinant Rift Valley fever virus N protein for the detection of IgG and IgM antibodies in humans and animals by indirect ELISA." J Virol Methods. **140 (1-2)**: 106-14.

Vialat, P., R. Muller, et al. (1997). "Mapping of the mutations present in the genome of the Rift Valley fever virus attenuated MP12 strain and their putative role in attenuation." Virus Res **52**(1): 43-50.

Vrbova, L., C. Stephen, et al. (2010). "Systematic Review of Surveillance Systems for Emerging Zoonoses." Transboundary and Emerging Diseases: 8.

WAHAD OIE (2010). Rift Valley fever, Botswana. Paris, OIE.

WAHID OIE. (2007). "Rift Valley fever,Kenya." Retrieved 12/07/2007, from http://www.oie.int/wahis/public.php?page=single_report&pop=1&reportid=4487.

WAHID OIE (2010). Rift Valley Fever , South Africa. Paris, OIE.

WAHID.OIE. (2008, 08/02/2008). "Rift Valley fever South Africa." from http://www.oie.int/wahis/public.php?page=single_report&pop=1&reportid=6780.

WAHID.OIE. (2008, 22/12/2009). "Rift Valley fever,Madagascar.", from http://www.oie.int/wahis/public.php?page=single_report&pop=1&reportid=7629,.

WAHID.OIE (2008). "Rift Valley fever,Sudan." Retrieved 25/11/2008, from http://www.oie.int/wahis/public.php?page=single_report&pop=1&reportid=6637.

WAHID.OIE. (2009, 18/03/2009). "Rift Valley fever, South Africa.", from http://www.oie.int/wahis/reports/es_imm_0000007903_20090318_163808.pdf.

Wallace, D., C. Ellis, et al. (2006). "Protective immune responses induced by different recombinant vaccine regimes to Rift Valley fever." Vaccine **24**(49-50): 7181-7189.

Wallace, D. and G. Viljoen (2005). "Immune responses to recombinants of the South African vaccine strain of lumpy skin disease virus generated by using thymidine nkinase gene insertion." Vaccine **27;23(23)**: 3061-7.

Walter, M., K. Tabitha, et al. (2007). The impact of Rift Valley Fever on regional and international trade. OIE Workshop on Rift Valley Fever Control and preventive strategies, Cairo- Egypt.

Wanyoike, F. and K. Rich (2008). Socio-economic impacts of the 2007 Rift Valley fever outbreak in Kenya: a case study of the Northeastern province livestock marketing chain. CDC Rift Valley Fever worshop, Nairobi Kenya.

WHO. (1999). "Rift Valley Fever in South Africa." Retrieved 09/12/2008, from http://www.who.int/csr/don/1999_02_10/en/index.html.

WHO (2000). "Outbreak of Rift Valley Fever, Yemen." Weekly epidemiological record **75**(48): 385-396.

WHO. (2007). "Rift Valley fever Factsheet." Retrieved July, 2009, from http://www.who.int/mediacentre/factsheets/fs207/en/.

WHO. (2007, May 2010). "Rift Valley fever." Retrieved 4/12/2008, from http://www.who.int/mediacentre/factsheets/fs207/en/.

WHO (2007.) "Outbreaks of Rift Valley fever in Kenya, Somalia and United Republic of Tanzania,December 2006–April 2007." Weekly epidemiological record, **82**, 169-78 DOI: 0049-8114.

WHO. (2008). "Rift Valley fever - Sudan WHO update. ." Retrieved 13/11/2008, from http://www.who.int/mediacentre/factsheets/fs207/en/index.html

WHO. (2008). "Rift Valley fever in Madagascar.", from http://www.who.int/csr/don/2008_04_18a/en/index.html.

WHO. (2010). "Rift Valley fever in South Africa." Retrieved 01/04/2010, from http://www.who.int/csr/don/2010_03_30a/en/index.html.

Woods, C. W., A. M. Karpati, et al. (2002). "An outbreak of Rift Valley fever in northeastern Kenya, 1997-98." Emerging Infectious Diseases **8**(2): 138-144.

Youssef, B. and H. Donia (2002). "The potential role of rattus rattus in enzootic cycle of Rift Valley Fever in Egypt 2-application of reverse transcriptase polymerase chain reaction (RT-PCR) in blood samples of Rattus rattus." Egypt Public Health Assoc. **77(1-2)**: 133-41.

Zeller, H., D. Fontenille, et al. (1997). "Enzootic activity of Rift Valley fever virus in Senegal." Am J Trop Med Hyg **56**(3): 265-272.

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