Introduction

1.1. Background:

RVF is a serious infectious disease with severe clinical manifestationsand health consequences for humans and a wide range of domestic ruminants, caused by mosquito-borne virus that belongs to the family Bunyavirridae,genusphlebovirus.Virus transmission usually occurs either through the bite of an infected mosquito or by direct contact with infected animal tissues, body fluids or aborted fetal materials**(WHO,2016).**It was first reported amonglivestockinKenyain1931,sincethenithasbeenreportedasoccurringnot only inmost African countries, but also in Arabian Peninsula, particularly in Saudi Arabia and Yemen(**Daubney *et al*.,1931**)(**Madani *et al*.,2003**).

The first appearance of the RVF virus in new geographical areas outside Africa was reported in Jazan region, south-west Saudi Arabia in 2000, with 886 confirmed cases involving 124 deathsin humans**(Balkhy and Memish, 2003)**. This outbreak has raised concerns about the potential spreading of the disease in new geographical areas including Europe, Asia and Americas as a consequence of climate change and globalization of trade in animals and animal products(**Kim *et al*.,2016**).

Outbreaks of RVF have always been associated with periods of heavy rainfall that raises the level of water in dry wooded grasslands and floods the grassland depressions, resulting in increasing of mosquito populations which are thought to play a pivotal role in the life cycle and amplification of the virus during epidemics (**Davies *et al*.,1985**).Species of mosquito thatpreviously are incriminated as potential vectors for RVF vary between regions(**Turell *et al*.,2008***).*Several mosquito species serve as principal vectors and able to transmit the virus by bites,most notably thosebelonging to the genus *Aedes*whichis thought to play a significant role in maintaining the endemicity of the disease in the environment through transovarial transmission(**Rayah *et al*.,2016**).However, the prosperity of effective intervention depends on the early detection of the infectious diseases and rapid response mechanisms to emerging outbreaks, therefore, new technologies that

facilitate this matter are of great importance. Recently, geographical information system (GIS) has gained much more interest worldwidein public health, epidemiologyand surveillance programs.Additionally, mostProfessionals are becominghighly involved in GIS and increasingly dependent on integrated use of spatial information and dynamic analysis (**Mirzoev *et al*.,2015**).

GIS is a very useful tool in collecting, localizing, managing,monitoring and analyzing data, as well as, displaying the results of analyses on maps, tables and statistical diagrams**(Gosselin *et al*., 2005).**The application of GIS technology in control of infectious diseases that threaten the livelihoods of millions of people is promising. It can be applied to illustrate the distribution of infectious diseases, examine risk factors and detect populations at risk of infection, especially when integrated with Geographical Positioning System (GPS) and remote sensing technologies **(Soti *et al*., 2013).**GIShas been highly suitable for mapping disease spatial aspects, analyzing epidemiological data over a large spatial scale, revealing trends and visualizing problems to enhance decision making on prevention and intervention efforts (**Bhatt and Joshi, 2012).**

The implementation of GIS in veterinary activities that are mostly spatial in nature has been developed over the last decade. Most vector-borne diseases such as RiftValley fever, yellow fever, malaria and dengue, are strongly linked and highly sensitive to climate, which constrains the range of infectious diseases and affects the timing and distribution(**Martin *et al*.,2008**).Moreover , prospective risk mapping models using climate data could predict areas where outbreaks in animals and humans were expected, in order to improve outbreak response and intervention activities (**Anyamba *et al*.,2010).**

Since the early recognitionofRVF Saudi Arabia,a comprehensive control and prevention measures have been in place to minimize the spread of the disease in Jazan region including but not limited to insecticide land spray, aerial spray, entomologica

surveillance, virus detection in mosquitoes by molecular techniques, serological surveillance and sustaining vaccination campaigns.

Although these measures contributesignificantly toRVF control over the pastsixteen-years, there are still some gaps and significant limitations.The existing control measuresare obviously lacking the geographical perspective besides the absence of spatial aspects. Firstly,the currentmosquito surveillance efforts have focused mainly on mosquito's density at different sites irrespective of theiridentity. Furthermore, uncertainty regardingpotential habitats for RVF vectors might still exist. Secondly, thegeographical distribution of mosquitoesaccording to coordinateshas not yet been adequately addressed.Thirdly,the potential epizootic area for RVF as well as human and animal populations at risk of contracting RVFare not accurately defined.Finally, very little is yet known about the boundaries of intervention area, the spatial pattern and the extent of the disease.Consequently, according to the above-mentioned limitations, there is an adequate justification for an entomologic investigationin the whole region to identify the distribution of RVF vectors according to geographic coordinates as well as a GIS system to facilitate collecting, managing, interpreting, andmost importantly displaying the results of analysis on maps.Based on RVF associated factors and according to the mapping capabilities of GIS and its ability to combine multiple individual layers of data into a single map, high risk areas that may be prone to outbreaks and the spatial boundaries of intervention area will be easily identified.

The study strives toprovide new insight into disease controland contribute to establishinga forecasting system for RVF along withstrengthening surveillance and response system effectively over the long time.

Research Objectives:

General Objectives:

1- To identify potential epizootic areas for RVF and the boundaries of intervention activities.

2- To establish a forecasting system model for RVF, to predict areas with potential risk of the disease outbreaks.

3- To examine the distribution of RVF competent vectorsaccording to geographical coordinates especially of the genus *Aedes*

4- To investigate the existence of RVFV in mosquitoes by molecular techniques.

Specific Objectives:

1- To establish mosquito database, as it will be used as a platform for controlling emerging mosquito-borne diseases.

2- To create a powerful tool for monitoring and managements of epidemics.

3- Toimprove the quality of data by establishing a database system able to organize and store data, perform analysis and produce maps in addition to tables.

4- To identify locations where people are potentially exposed to RVF.

5- To calculatethe total population who arepotentially exposed to RVF.

Chapter One

Literature Review

1.1.Etiology and transmission

Rift Valley fever is a life-threatening disease of domestic ruminants and humans, included in OIE list as a notifiable and transmissible disease of serious socio-economic impacts and public health concerns**(OIE,2015).** The causative agent is Rift Valley Fever virus (RVFV), belongs to the family Bunyavirridae, genus phlebovirus **(WHO,2016).**

Humans can be infected either by mosquito bites or through exposure to blood, body fluids or infected animal tissues during slaughtering or butchering, assisting with animal births, conducting veterinary procedures, or from the disposal of carcasses or fetuses. The virus infects human through inoculation via a wound or inhalation of infected aerosols. Human infections ranged from mild to fatal hemorrhagic with probable late complication of encephalitis or ocular disease(**WHO,2016**). Although the virus has a potential to infect a wide range of animals including goats, cattle, camels, dogs, cats, and ferrets, it has been recognized as acute and fatal disease in new born lambs and known as causing high rates of abortion in pregnant ewes as well (**Ikegami and Makino, 2011)**.

1.2.Socio-economic impacts of RVF outbreaks

RVF is a growing public health concern, resulted in hundreds of thousands of humans infection, causes serious socio-economic consequences and destruction of international animal's trade. The socio-economic impact of the RVF epidemics has been higher especially to populations that were totally dependent on livestock as source of income.

Studies quantifying the socio-economic impact of RVF outbreaks are still lacking.In Kenya, for example, during 2006 /2007 outbreak the total economic losses from livestock mortality and potential milk production were calculated at over (US$9.3 million) and (US$77,000) respectively. The negative impacts not only affecting livestock producers, but also extended to various stakeholders in the marketing chain including livestock traders due to unsoldanimals during quarantine, slaughterhouses casual laborers and butchers who were affected by imposition of slaughter bans during outbreaks **(Rich and Wanyoike, 2010)**. Furthermore, it seriously affects household nutrition due to loss of livestock and restriction of live animal movements, as well as, the ban imposed on slaughterhouses.

In Tanzania the loss as a result of animal death was estimated at around (US$4,243,250) for cattle and (US$2,202,467) for sheep and goats. Moreover, the sales of livestock and meat industry were also impacted by decrease in consumer demands and trade restrictions **(Sindato *et al*.,2011).**

1.3. RVF competent vectors:

Outbreaks of RVF have always been associated with periods of heavy rainfall that raises the level of water in dry wooded grasslands and floods the grassland depressions, resulting in increasing of mosquito populations which are thought to play an important role in the life cycle and amplification of the virus during epidemics(**Davies *et al*.,1985**).

Striking differences among mosquito species thatinvolved in vectoring RVF virusin Africa and Arabian Peninsula. Species of mosquitoes that are incriminated as principal vectors and have apotential to transmit RVFV via bites vary between regions**(Turell *et al*., 2008).** In Saudi Arabia, Of seven mosquito species detected in Jazan region during the 2000 epidemic, only two speciesincluding *Culex .tritaeniorhynchus* and *Aedes. Vexans arabiensis* were confirmed as the principal vectors responsible for the transmission and

spreading of RVF virus through animals and humans**(Jub *et al*.,2002).**The most abundant culicine mosquitoes collected in Asir region in the same outbreak wereAe. vexans arabiensis, Cx. pipiens complex, and Cx. tritaeniorhynchus.All these three species should be considered as an importantepidemic and epizootic vectors of RVFV in Saudi Arabia (**Miller *et al*.,2002**).

In Kenya, ten species were tested positive for RVF virus during 2007 outbreak, including *Aedes mcintoshi/circumluteolus* ; *Aedes ochraceus ;Mansonia uniformis Culex poicilipes; Culex bitaeniorhynchus; Anopheles squamosus, Mansonia africana Culex quinquefasciatus; Culex univittatus; Aedes pembaensis* (**Sang *et al*., 2010).** These findingswere predated by **(Linthicum *et al*.,1985)** who isolated RVFV from : *Aedes. lineatopennis, A.cumminsii, A. pharoensis)(Culex, antennatus, Cx. vansomereni. Cx. Zombaensis, Cx. rubinotus- near grassland depressions.). (Anopheles. christyi).*

Turell*et al*.,(2007) under laboratory conditions in the Lake Naivasha region of Kenya found that,*Cx. Zombaensis* was highly susceptible to infection with RVFV (89% of mosquitoes become infected). 48% of the infected mosquitoes were able to transmit the virus by bite**.**Subsequent trials were performed in USA in 2008 to study the potential for American mosquitoes to transmit *RVFV. Ae. taeniorhynchus, Ae. vexans, and Cx. erraticus* were found efficient vectorsafter they fed on hamsters with viremia between 10(8.5) and 10(10.2) PFU/ml, at 26 ºC for 7-21 days. Both of *Ae. vexans and Cx. erraticus* transmitted RVFV by bites**(Turell *et al*.,2008).**

In Sudan, during the 2007 outbreak, RVFV was detected by RT-PCR techniques in, larva and female of *Anopheles gambiae arabiensis ;Ae. Aegypti;Culex. Pipiens; Culex.poicilipes;and Anopheles coustani* in White Nile State. Meanwhile, *Cx.pipiens complex* was the most abundant species (91.2%) in Khartoum state. Surprisingly, RVFV was detected in two male samples of *Anopheles gambiae arabiensis*collected from the White Nile State,suggested that the virus is likely transovarially transmitted(**Seufi and**

Galal, 2010). In Egypt, it was assumed that *Ae. Caspius,*appeared to be the most efficient vector in Egyptduring outbreaks. While*Cx. Pipiens*, *Cx. Antennatus*, and *Cx. Perexigus* were alsoconsidered as potential vectors for RVF but to a lesser extent than Ae. Caspius (**Turell *et al*., 1996).**

In South Africa, the virus was isolated from infected farm in Plateau region during epizootics in 1974and 1975. *Cx. theileri* was found the main epizootic vector among sheep and cattle.*Ae.juppi* and *Ae. Lineatopennis* act as vectors of lesser extentunder laboratory conditions(**McIntosh *et al*.,1980**).It is noteworthythat, in West Africa RVF vectors were different from the main ones in East and South Africa. The virus was isolatedin a bordering region in Senegal from *Aedes vexans* and *Ae. Ochraceus* in 1993, and from Ae. *Dalzieli* in 1974 and 1983; from *Culex poicilipes*in Oct 2003**(Fontenille *et al.*,1998)(Faye et al.,2007)**.In Senegal from 1991 to 1993, RVFV was isolated from *Aedes vexans* and *Ae. ochraceus* mosquitoes collected from traps near ground pools In Barkedji area (**Herve,1997**).

The potential vectors for RVF in countries of the Mediterranean basin were investigated experimentally by **Moutailler *et al*.,(2008**).Three mosquito species collected from southern France and Tunisia(*Aedes caspius, Aedes detritus, Culex pipiens*); and from different laboratory-established colonies (*Aedes aegypti, Aedes albopictus, Aedes vexans, Anopheles gambiae, Culex pipiens, Culex quinquefasciatus*), were evaluated to disseminate two different strains of RVFV,the virulent *ZH548* and the avirulent *Clone 13*. Among field-collected mosquitoes, *Cx. pipiens* was found the most efficient vector with disseminated infection rates ranging from 3.9% to 9.1% for French strains and up to 14.7% for Tunisian strains. Whereas *Ae. aegypti*(from laboratory-established colonies) exhibited the highest disseminated infection rates 90% when infected with ZH548 and 72.6% with Clone 13(**Table 1.1**).

Table 1.1 : potential RVF sylvatic vectors in endemic zones

Country	competent vectors	Date	Reference
Kenya	*Aedes.lineatopennis; Ae.cumminsii;* *Ae.pharoensis ; Culex, antennatus* *Cx.Vansomereni; Cx. Zombaensis;* *C. rubinotus; Anopheles. christyi*	**1981-1984**	**(Linthicum *et al.*,1985)**
Kenya	(*Aedes mcintoshi/circumluteolus ;* *Aedes ochraceus ; Aedes pembaensis; (Mansonia uniformis; Mansonia Africana; Culex poicilipes;* *Culex bitaeniorhynchus ;Culex univittatus; Culex quinquefasciatus;* *Anopheles squamosus*	**2007**	**(Sang *et al.*, 2010).**
South Africa	*(Cx. Theieri ;Ae. Jupp; Ae. Lineatopennis*	**1974**	**(McIntosh *et al.*,1980)**
Mauritania	*Aedes vexans ; Ae. Ochraceus and Ae. Dalzieli*	**1974 and 1983**	**(Fontenille *et al.*,1998)**
	Culex poicilipes	**2003**	**(Faye *et al.*,2007).**
Egypt	*Ae. Caspiu; Cx. Pipiens; Cx. Antennatus; and Cx. Perexigus*	**1977 and 2003**	**(Turell *et al.*, 1996).**
Sudan	*Culex. Pipiens; Culex.poicilipes ; Ae. Aegypti Anopheles gambiae arabiensis; Anopheles coustani*	**2007**	**(Seufi and Galal, 2010)**
Saudi Arabia	*Culex .tritaeniorhynchus ; Aedes. Vexans; arabiensis*	**2000**	**(Jub et al.,2002)**
Senegal	*Aedes vexans and Ae. ochraceus*	**1991-1993**	**(Herve,1997).**
Madagascar	*An. coustani ; An. Squamosus* *Cx. Antennatus*	**2009**	**Ratovonjato*et al.*,2011**

InMadagascar, mosquito species that could act as RVFV vectors were investigated in April 2009, after veterinary alerts of RVF in districts of Fianarantsoa and Ambalavao. Laboratory results indicated that *An. squamosus, An. coustani, and Cx. antennatus* could play a role as vectors of the RVFV during the disease outbreaks in 2008–2009(**Ratovonjato *et al*.,2011**).

1.4.Historical outbreaks of RVF

Since the disease was first isolated in Kenya in1931, several outbreaks affected animals and humans have been reported in much of sub-Saharan Africa, mainly and more frequently in Kenya, Somalia and Tanzania **(WHO,2016).** Historically, major epidemics have been reported most notably in Kenya (1997/1998,2006/2007),Tanzania (2007), Somalia (2007), Saudi Arabia and Yemen (2000/2001), Mayotte (2008), and Mauritania (2010, 2012) (**Nanyingi *et al*., 2015).**

Egypt has suffered from several RVF outbreaks,the most devastating epidemic was recorded in 1977, causingan estimated 600 human deathsas well asthousands of abortions in domestic animals(**Meegan *et al*.,1979**).Subsequent outbreaks in Egypt occurred in 1993 and then in 1997 in Aswan and Asyut provinces,it was attributed to importation of infected ruminants specifically camels(**Arthur *et al*.,1993**),(**Abd *et al*.,1999**).A more recent extensive outbreak was reported in Kafr el Sheikh governoratein 2003, with 29 confirmed human cases(**Hanafi *et al*.,2011**).

The first reported outbreak of RVF in Sudan occurred in 1973 in sheep and cattle following an exceptionally heavy rainy season,the highest incidence was reported in White Nile State (**Eisa *et al*.,1977**). After an interval of more than three decades, further epizootic was reportedin 2007, during extremely heavy rainfall events inWhite Nile, El Gezira, and Sennar states, where a total of 747 confirmed human cases were reported,including 230 fatalities (**Hassan *et al*.,2011**).

In South Africa,several economically devastating outbreaks of RVF have been recognized in humans and animals since 1950.Three major epidemics were subsequently invaded the country reported in (1950/1951-1974/1975-2010/2011) (**Pienaar and Thompson, 2013**).

Despite there are only a few reports of RVF in West Africa, Mauritania has experiencedseveral RVF epidemics responsible for severe losses both in humans and domestic animals. In 1987, a major RVF outbreak has occurred in Mauritania,resulting in abortion in domestic animals as well as clinical syndromes ranging from uncomplicatedto hemorrhagic diseasein humans(**MONDO *et al*.,1995**).In the last decade, an unprecedented RVF outbreak was documented in the northern Sahelian region of Mauritania between September-October 2010, afteran extremely heavy rainfall.Unexpectedly, the virus was amplified in dromedary camelswith high mortality rates and sever clinical signs (**El Mamy *et al*.,2011**)(**Figure,1.1**).

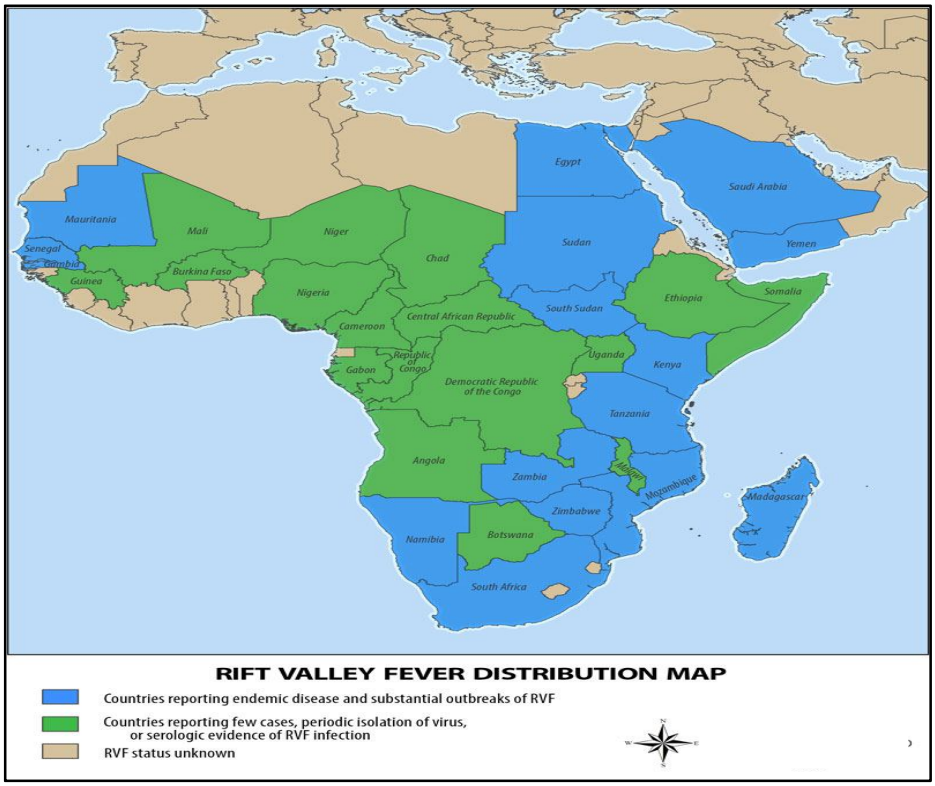


Figure 1.1 (**CDC, 2013**)

Interestingly, RVF activity in Mayotte appears to be an expansion ofthe eastern Africa outbreaks. As recent as 2008, ten RVF human cases were detected in Mayotte through a retrospective and perspective study conducted to analyze serum samples from febrile patients to assess the situation of RVFV in humans subsequently after the detection of several positive cases in cattle in March 2008(**Sissoko *et al*.,2009**).

1.5.Clinical Signs and Host Range

Considerable variations in the level of susceptibility to RVFV ranged from in- apparent infections with no sickness or febrile to severe diseasewith high mortality. The susceptibility of different breeds to RVF varies significantly. Some indigenous animals may have only inapparent infections, while others clearly manifested clinical disease with high mortalities. Although RVFV is known to infect a wide range of domestic animals,sheep are assumed to be the primary amplifying hosts, followed in order bygoats, cattle and camels. Unlike domestic animals, the disease is commonly observedmild in buffaloes, but inapparent in horses, poultry, wild birds, rabbits and pigs(**Davies and Martin, 2003**).

The sudden onset with high rate of abortions among domestic animals over a large areaand high neonatal mortalities together with human cases are probably the most significant signs. In acute disease there is a very short incubation period commonly less than 24hours. Nearly, 100 percent of young lambs of susceptible breeds may die,whereasadult animals in a milking herds show a febrile disease with agalactia .Sub-acute disease is more likely in adult sheep, older animals at 1-4 month may suffer an acute febrile disease and 10-40% fatalities due to hepatitis and jaundice***(*Davies and Martin, 2003**).

Hepatic lesions are very similar in all species with some variations in the age of infected individual. The most severe lesion in aborted fetuses and newborn lambs is enlarged, soft friable liver with a yellowish-brown dark or reddish-brown color.In adult sheep, a pinpoint reddish to greyish-white necrotic foci are distributed in parenchyma. Additionally, hemorrhage and oedema are commonly distributed in gallbladder. The

content of the small intestine and abomasum are dark chocolate-brown. The spleen and peripheral lymph nodes are usually enlarged in all animals (**OIE,2014**).

1.6.RVF in humans:

Humans are highly susceptible to the RVF virus,they can be infected through mosquito bites or contact with blood, body fluids and infected animal tissues. Veterinarians, slaughterhouse personnel, butchers, animal workers and farm family members aremore vulnerable than others and increasingly at high occupational risk of RVF infection (**Turkistany *et al*.,2001**).

Clinical manifestations of RVF in humans are often not specific, humansare more likely to show either severe or mildform.In the mild form the incubation period ranges from two to six days,infected humans often suffer influenza like symptoms with fever, muscle pain, joint pain and headache. Some patients develop neck stiffness, sensitivity to light, loss of appetite and vomiting. These symptoms usually last for four to seven days, full recovery in two weeks.

The severe form of the disease has rarely been reported, only 1-2% of cases progress to severe disease.This usually appears as one or more of three distinct syndromes: ocular (eye) disease (0.5-2% of patients), meningo-encephalitis (less than 1%) or hemorrhagic fever (less than 1%) (**WHO, 2016**). Surprisingly, the hemorrhagic cases of RVF usually occurred among human populations of the alluvial flood plain zonesprincipally in semi-arid regions.The susceptibility of such populations to highly Fatal Hemorrhagic Syndromecan probably be attributed to chronic immunosuppressive diseases(**Davies, 2010**).

Hepatic necrosis is most obvious lesion in humans and animals, during the 2000 outbreak in Saudi Arabia. The main factor leading to deaths could be considered to be hepatocellular failure(75.2%),followed byacute renal failure (41.2%,). However, a small

percentage of people developed much moresevere signs including, hemorrhagic manifestations, retinitis, meningoencephalitis and death (19.4%, 9.7%, 4.2% and 33.9%) respectively**(Al-Hazmi *et al*.,2003).**

The worst RVF outbreak in terms of human mortality was reported in Sharqiya Governorate, EgyptIn 1977, withthousands of human cases and nearly 600 human deaths. The major clinical signs appeared as, acute febrile dengue-like illness, encephalitic, ocular and fatal hemorrhagic disease (**Meegan, 1979**).

1.7. Epidemiology of RVF

It was assumed that during inter-epizootic period there was an endemic cycle for RVFbetween mosquitoes and vertebrate host. Female*Aedes* mosquitoes can pass the virus to their eggs and offspring by transovarial transmission.Surprisingly, the virus could be maintained viable for several years during dry conditionsby a period of dormancy in the eggs of *Aedes*spp.As a consequence,newly emergedadultsthat hatched from eggs would be already infected with RVFVand able to transmit the virus by bites to susceptible hosts**(Linthicum *et al*.,1985).**

Historical information has shown that, outbreaks of RVF have always been associated with periods of unusual and persistent rainfall that raises the level of water and floods the grassland depressions sufficiently to produce standing water in (dambos), that are the habitat of the immature forms of the genus *Aedes*. This floodingprovides an ideal habitats for oviposition and enables more mosquito eggs to hatch andthe subsequent Mosquitoesmight be infected with RVFV and able to transmit the virus to exposed animals located around water poolsresulting in high viremia(**Davies *et al*.,1985**).

The persistence of water in pools for more than four weeks constitutes a favorable environment for the secondary vector mosquitoes such as *Culex, Aedes, Anopheles,* and

mansonia, as well as, other biting flies:*Culicoides spp, Stomaxy spp, glossina* spp and *tabanids*-to breed rapidly and increase dramatically to produce huge vector populations able to transmit RVF mechanically to a large extent beyond the outbreak area (**Davies and Martin, 2003**).

1.8.Epizootic and epidemic Cycle:

There are two different types of secondary cycles, by which RVFV is transmitted to humans:the sylvatic cycle andthe urban peridomestic cycle**.** In the peridomestic cycle humans in urban areas become infected with RVF through the bites ofanthropophilic mosquitoes. Whilein sylvatic cycle, humans working in livestock industry acquire the infection through contact with animals to whichthe virus has been transmitted by zoophilic mosquitoes. There appears to be little contact transmission betweenanimals in spite of the presence of virus in nasal dischargeand saliva**(Gerdes, 2004).**

Transmission cycle of Arboviruses are strongly influenced by three overlapping factors including the virus, the arthropod vector and the vertebrate host. Nearly, 30 mosquito species might be involved in RVF transmission or maintaining endemicity.The sequence of RVFVinfection in mosquito organs and tissues when a competent mosquito ingests viremic vertebrate blood,involves two steps: firstly, the virus infects midgut
epithelial cells and replicates. Secondly, the virus disseminates to other tissues includinghemolymph, remnants, salivary glands, ovaries, and thoracic ganglia.In fact, not all mosquitoes that ingest virus become infected or, if infected able to transmit viruses. Several
barriers to arbovirus passage have been identified in incompetent or partially competent mosquitoes, including, gut escape barriers and salivary gland infection barriers. Both of The extra cellular basal lamina around the midgut epithelium and the basal lamina surrounds salivary glands may act as such barriers (**Romoser *et al*.,2005**)(**Faran *et al*.,1988).**

The ability of mosquitoes to vector arboviruses depends on intrinsic and extrinsic factors. The formerinclude mosquito host preferences, the ability of mosquito to become

infected after ingestion of an infected blood meal, the ability of mosquito to transmit virus by bite or through the eggs and environmental temperature.On the other hand, the extrinsic factors involvethe availability of suitable vertebrate host, density of mosquito and vertebrate populations and environmental conditions (**Hardy *et al*.,1983**).

1.9.Mosquito FeedingBehavior:

With the exception of *Aedes /Ochlerotatus spp*, all mosquitoes need aquatic habitats and stagnant puddles to breed successfully during the larva and pupa stages.As most mosquito species are unautogenous, adult femaleshave to take more than one blood meal from an animal or human to stimulate egg-laying. However, male mosquitoes unlike females,theyplay almost no role in virus circulation in mosquito vectorsand limit their feeding to plant juices and nectar. Despite the fact that female mosquitoes often mates only once and store the sperm for future eggs, malescan mate many times per breeding season (**Becker *et al*.,2003*)(*Foster and Walker, 2002**).

Females are thought to locate a host within habitat zone by a random motion in search of carbon dioxide that mosquitoes can sense from hundreds of feet away. Lactic acid, acetone butanone and phenolic compounds are the most mosquito chemical attractants that emanated from skin tohelp mosquito in flightorientation toward a host during host seeking process(**Kline *et al*.,2012**). When a mosquito becomes closer to the host the compound eyes can discriminate between forms, colors and light contrast. Thethermal sensors on the insect's antennae and around its mouth can detect heat from warm-blooded bodies, allowing it to land on exposed skin(**Becker *et al*.,2003**).

As with most dipterans, the head of adult mosquitoes has three appendages: antennae, maxillary palps, and proboscis.Experimental studies demonstrated that proboscis are requiredfor both host recognition and sharingfunctional roles withantennae and maxillary palpsin sensing attractants and stimulant factors, leading to the capture of host

during host feeding process(**Maekawa *et al*.,2011**).The proboscis contains the mouthparts which in turn include the labrum, paired mandibles, hypopharynx, paired maxillae, fascicle and labium. The hypopharynx releases saliva that contains anticoagulant and the apyrase enzyme in order to flow blood freely. During the blood feeding process, the fascicle is inserted in to the vessel to draw the blood in the midgut using the pharyngeal pump. Following that, the abdominal receptors signal the mosquito to stop and use her forelegs to remove the fascicle from the skin host(**Foster andWalker, 2002**).Before becoming fully engorged on blood, a female begins to excrete fluid from her anus and continues to do so for 2 hours after completing the meal. Finally, the female seeks for a suitable resting site to digest the blood mealand rapidly take another meal 2 to 5 hours after the first (**Jones and Pilitt, 1973**).

Oviposition is an important component of most mosquito-borne diseases, whichdepends on environmental factors especially rainfall, temperature, relative humidity and wind speed. The transmission of arboviruses from a host toa competentvector usually requires one blood meal, Whereas, virus transmission to susceptible host requires at least two blood meals (after the completion of at least one oviposition cycle)(**Bentley and Day, 1989**).

1.10.Diagnostic tests for RVF:

Efficient and accurate diagnosis for RVF not only relies on the purpose of the testing and the history of the disease, but also on the clinical signs along with epidemiological information. According to**OIE,(2014**) diagnostic tests for RVF should include the following tests:-

1.10.1.Identification of the agent:

To isolate RVFV fromblood with anticoagulantor approximately 1cm3 of liver or spleen, aborted fetus and brain; samples should be collected during the febrile stage of live

animals. Primary isolation is usually performed in cell cultures such as African green monkey kidney (Vero), baby hamster kidney(BHK) and AP61 mosquito cells. Then, the supernatant fluid is injected intracerebrallyin sucking mice 1-5 day old. The Sucking mice will either die or be obviously ill by day 2 post-inoculation.(**OIE,2014**).

1.10.2 Reverse-transcription polymerase chain reaction

The conventional and real-time RT-PCRtests which werevery useful during RVF outbreaks in Africa, can be used todetect RVFV in mosquito as well.

1.10.3 Histopathology

The test allows the specific identification of RVF viral antigen in tissue through cytopathological lesions in affected tissue. It is very useful in transporting samples from remote areas as suspected tissues can be placed in neutral buffered formaldehyde in the field and it doesn't require a cold chain(**OIE, 2014**)

1.10.4.Serological Tests :

Several assays are available for detection of anti-RVFV in a variety of animal species. However, the two most widely used are the Enzyme linked Immune Absorbent Assay (ELISA) for the detection of IgM and IgG and virus neutralization tests (VNT) (**OIE, 2014**).

1.10.4.1.Enzyme-Linked Immunosorbent Assay

The ELISA is a safe, robust and highly accurate diagnostic test for RVF surveillance and control program(**Paweska *et al.*, 2005**).Although, It was known as more sensitive and highly accurate in early diagnosis of infectionor vaccination with RVF, its sensitivity declined over time (**Paweska *et al.*,2003**). Both IgG and IgM are available for most species. They are used routinely in endemic countries for single case diagnosis, outbreak

management and surveillance. TheIgM-capture ELISA allows diagnosis of recent infections.

1.10.4.2.Virus Neutralization

The VN is a highly specific test that can be used to test serum and detect antibodies in all animal species to determine the presence of antibodies in naturally infected animals and in vaccinated animals. It iscommonly used to measure vaccine efficacy. It is highly specific with little or no cross-neutralization with other phleboviruses. Unlike ELISA test, VN requires the use of live virus, therefore it is not recommended for use outside endemic countries unless a high level of biocontainment is available in laboratories*(***OIE,2014**).

1.11. Prevention and Control of RVF

Control measures should be implemented during inter-epizootic period can include the following:sentinel herd monitoring, entomological surveillance, sero-surveillance, preventive vaccination,vector control and Remote sensing data towards establishing an Early Warning System. However, whilst an outbreak time of RVF it has been suggested that vector control, public education, animal movement control,quarantine, and slaughter ban,are probably the most effective measures against the disease (**FAO, 2003**).

Increasing public awarenessamong vulnerable populations to enable them participate actively in implementing vector control along withimproving people adherence toself-protective measures,are probably the key to preventing RVF in humans. The possible preventive measures can be summarized as follows:1) wearing protective equipment over as much of the body as possible to avoiddirect contact with suspected animals, body fluids or aerosols. 2) use of mosquito repellent.3) sleeping underInsecticide-treated bed nets (ITNs).4)indoor spraying of houses with residual insecticides.5) compliance with the standard precautions amonglaboratory workersand

healthcare workers who care for patients with suspected or confirmed RVF(**Smithburn et al.,1949**).

1.11.1. vector control

The environmental and demographic changesover the last decadeshave created conditions favoring breeding of vectorsand increasing mosquito population densitiesresulting in the emergence of new life-threatening diseasesand the resurgence of serious outbreaksin more virulent forms(**Gratz, 1999**). Since, effective vaccines or treatment were not always available for the prevention of these diseases, vector control is considered as one of the major componentsof preventing mosquito-borne diseasesinhighly exposed populations.Itcontributes significantly to breaking the chain of epidemic cycleand reduction of disease transmission between and within animal species(**Rozendaal,1997**)

Multiple options are available and widely used in controlling mosquitoes including chemical control compounds, biologicalagents and mechanical methods.Insecticide spraying at ultra-low volume (ULV)with oil or water based spray solutions can effectively reduce the abundance of adult mosquito andinterrupt the amplification and dispersal of RVFVwhen applied correctly under required conditions. The ULV devices can be mounted on trailers, trucks or aircraftswith small quantities of pesticide active ingredient in relation to the size of targeted area. Apart from the ULV spraying, thermal fog equipment with diesel based solutions aerosolize the insecticides by heat to provide immediate control for adult mosquito when applied at the time of flight activity.Most importantly, all chemical insecticides should be approved at local and international scale by**WHO and FAO.** Several public health adulticides are commonly used to maintain low vector population density, including organophosphates such as Malathion and Naled as well as pyrethroids like Permethrin, Resmethrin, Sumithrin, Prallethrin and Etofenprox(**EPA,2016**). As adult mosquitoes are highly mobile with ability to avoid many intervention measures,control of immaturestages could be highly effectiveat controlling mosquito populations and completely safe to other non-target organism,notably,when breeding sites are clearly

identified, easily accessible and limited in size and extent**(WHO,2016).**(**Killeen *et al*.,2002).**The natural vector predators such as bacterial toxins or botanical compounds are commonly used in control of vector populations.Theycome in different forms involving liquids,tablet, pellet, granular, and briquette. Theycan be applied directlyto water through backpack sprayers, truck or aircraft.Additionally, entomological surveys to guide vector control measures is essential bothbefore and after insecticide treatment to evaluate the larvicidal efficiency**Anyamba *et al*.,2010)**

On the other hand, environmental management is not only reducing the burden of environment pollution and pharmaceutical residues, but alsoapplying an effective approach to maintain permanent control of mosquito via altering or removing vector breeding sites. Methods and techniques of environmental management including,draining water to follow the natural flow, backfilling ditches with soil or stones, flushing streams, subsoil drainage, covering water containers, growing Eucalyptus trees, expanding polystyrene beads, removal of small used cans or tires, and removing vegetation from water bodies(**Rozendaal, 1997**).

Self-protectionmeasures used by individuals or group of people are both simple in use and effective inpreventing transmission of mosquito-borne diseases,as a consequence of reducingproportion of mosquito bites, particularly when these measures are applied over a large scale. Various forms of personal protection methods with small and simple equipment are commonly used including: repellents- protective clothing- insecticide vaporizers-mosquito coils-vaporizing mats-electric liquid vaporizers- pressurized spray cans-spray gun-mosquito nets(**Rozendaal,1997**).

1.11.2. Vaccines and Vaccination Against RVF

Like other viral diseases, the prevention of RVF relies heavily on immunization of susceptible herds in endemic and high risk areas during inter-epizootic periods with safe

and cost- effective vaccine, that is able to confer long-term protective immunity(**Bird, and Nichol,2012).**Although, several adverse effects have been associated with vaccination including injection site reactions, systemic and allergic reactions, residual pathogenicity and genetic recombination(**Martinod,1995),**thenumerous advantages and the benefits derived have promoted the use of vaccines rather than chemotherapy. Apart from the fact that vaccination is the onlyavailable method to prevent viral infections in the absence of broad spectrum antiviral, itis mostly environmentally friendly and contribute indirectly to preventing drug resistance and pharmaceutical residues in food(**Pastoret and Jones, 2003*).***Furthermore, it has significant impacts not only on reducing losses or improving health and production, but also on human health through increasing safe food supplies and preventing zoonotic diseases **(Meeusen *et al.*,2007).**

Generally, live attenuated vaccines are more preferable to inactivated ones, since only a single dose isrequired to provide a long-term immunity. The live attenuated vaccines are recommended inendemic zones and considered the primary available option for controlling the disease in high risk areas duringinter-epizootic period or at an outbreak early warning phase. Whileinactivated vaccines are advisable in free low risk zones and free high risk areas**(OIE,2014).**However, during an outbreak time of RVF, vector control, public education, quarantine, and slaughter ban probably are the most effective measures against the disease.

Obviously, the commercial production of RVF vaccines tends to be the biggest challenge, as the cost of sustained vaccination campaigns against RVF is beyond the capacity of most countries suffering regular outbreaks. Additionally, outbreaks of RVF usually occurred atirregular intervals and most commonly following exceptionally
epizootic periods which in turn both decreases the demand for vaccines and prevents the manufacturers from maintaining strategic stocks due to limited shelf-life**(Alhaj,2016).**

It could be argued that reliable information about vaccination in endemic zones is scarce.With the exception of Saudi Arabia, South Africa and Egypt, all affected countries

had notpracticed routine vaccination**.**In Egypt control of RVF is based on alternationbetween live and inactivated vaccines concurrent with periodical vector control. Live vaccine which has been used at intermittent periods, before, during or after outbreaks in an unidentified manner might be a significant factor in disease persistence and maintaining endemicity of RVF inEgypt **(Kamal, 2011).**In Saudi Arabia live attenuated vaccine (Smithburn strain) has been used as the gold standard vaccine for several years and seems to play a significant role in control(**Alfadil *et al*.,2004**).

Currently, two main types of vaccines with different development techniques are available for immunization against RVF, including, live attenuated vaccines and in-activated vaccines (**Ikegami and Makino,2009**).Attenuation of live vaccines was accomplished by in-vitro passage through a series ofcell cultures so as to produce a version of a virus attenuated to such a level that renders the virus unable to causedisease in animals, together withinducing a rapid onset of long lasting immune response similar to that of natural infection. Inactivation is obtained by growing the virus in culture media before being treated with heat or chemicals such as Formalin to destroy the ability of viruses to replicate (**CDC, 2012**).

Although, inactivated vaccines are biologically safe, more stable and haveno residual viruses or risk of reversion as attenuated vaccines (**Barteling andWoortmeyer 1984),** they are still known to beless protective, needed high antigenic mass and strong adjuvant to stimulate the immune system. Moreover, they continued to be associated with slow onset of immunity, localreactogenicity, risk of incomplete inactivation, hazards to personnel, as well as, not very efficient without multiple injections(**Minke *et al*.,2004**).

1.11. 3 Commercial Vaccines Against RVF

To date, there is no licensed vaccine against RVF available to immunize humans, whilevarious strains for livestock now are licensed and commercially produced including

Smithburn vaccine, Formalin-inactivated vaccine and Clone13. These vaccines are produced by three different laboratories: Onderestepoort Biological Products limited (OBP) in South Africa,Kenya Veterinary Vaccine Producing Institute (KEVEVAPI), and Egypt's Veterinary Serumand Vaccine Research Institute (EVSVRI**)**

1.11.3.1. Smithburn Vaccine:

Smithburn Vaccine Strain was derived from the virulent Entebbe strain, isolated from mosquitoes in Uganda and developed by serial passages in mouse brains to be able to induce immunity in ewes and their offspring after subcutaneous inoculation (**Smithburn,1949).**

Currently, producedin OBP and KEVEVAPI in freeze-dried form,the recommended dose is 1ml of thereconstituted vaccine administered via subcutaneous route for the immunization of sheep, goats for OBP vaccine whereas cattle received 2 ml of RIFTVAX TM vaccine compared with 1ml of Rift Valley Fever(Live) produced at OBP. According to manufacturer's instructions, the vaccine can cause abortion or fetal malformation in a small percentage ofanimals, particularly sheep, as well as, a slight febrile reaction may occur on the second tofourth day following inoculation **(OBP,2016).**

Despite, these adverse outcomes, it has been widely used for many years as the major prevention measure as a cost-effective vaccine inmost endemic zones, since the first introduction of the virus (**Davies,2010**). Likewise, in Jazan regionSaudi Arabia, it has been used as the gold standard vaccine for several years as a prevention measure, since 2000 outbreak. It has also been proved through serological surveys to be effective and highly beneficial in controlling infections, as no notable clinical signs in animals have been reported yet(**Abdelhamid and Sami,2006**).

1.11.3.2. Formalin-Inactivated Vaccine

The lyophilized vaccine containing 2% Human Serum Albumin was first prepared in African green Monkeys Kidney cell and proved to be safe, immunogenic and highly resistant tothermal deterioration(**Randall *et al.*,1964**). Commercially produced from OBP and EVSVRI, the virus strainadapted for growth in baby hamster Kidney(BHK-21)cell, with aluminium hydroxide gel adjuvant for immunization of cattle , sheep, and goats, irrespective of the age and stage of pregnancy(**OBP,2016**). A safe version of inactivated vaccines with minor side effects named TSI-GSD 200, was developed in USA by using a new master seed of the Entebbe strain. The vaccine is neither licensed for use in human nor commercially available, but has been used to protect personnel who either work in laboratories with RVFV or would be exposed to RVF infection (**Pittman *et al.*,1999**).

The safety and efficacy profile of inactivated vaccines have been further investigated in several trials. The immunization of susceptible cattle, sheep and goats with
inactivated vaccine would induce higher neutralizing antibodies which persist for 9 months in cattle with evidence of protections against RVFV in pregnant ewes(**Barnard and Botha,1977).**A comparative study conducted to assess the response in cattle to live and inactivated RVF vaccines revealed that, a booster dose of inactivated vaccine after 3 months of the first vaccination was safe and able to evoke a good response sufficient to protect cattle againstRVF for at least 1 year(**Barnard, 1979).**

1.11.3.3. Clone13 Vaccine:

Although, Formalin-Inactivated vaccine and live-attenuated Smithburn vaccine are widelyused in control, both of them are accompanied by significant concerns. The first one requiresmultiple doses for protection, and the second has a risk to cause abortion and fetal malformation in pregnant animals (**Indran and Ikegami, 2012**). Drawbacks of these vaccines stressed the need for alternative vaccines in terms of safety and efficiency.

Consequently, a massive progress and several initiatives have been done for the evolution of modern vaccines.

Recent studies haveshown that, RVF virus vaccines containing deletions of the NSs and NSm genes are highlyattenuated, confer protective immunity with no detectable viremia and could be useful in control of RVF virus in endemic regions, as well as, allow for DIVA(**Bird *et al.*,2008**). The commercialOBP vaccine which is named (RVF Clone13)has recently been registered, marketed in a form of Freeze-dried live attenuated virus (clone13 strain) and extensively used in South Africa (**Kortekaas *et al.*,2011**).Clone13 is a naturally attenuated isolate of RVF virus with a large deletion in the S segment.It was cloned by plaque purification of non-fatal human case isolate (74HB59 strain), obtained during 1974 RVF outbreak in Central African Republic and proved to be highlyimmunogenic leading to long-term immunity as well (**Muller *et al.*,1995**).

Although, the currently available commercial vaccines have made a great contributions to RVF control over the past 80years, they are associated with some safety and efficacy concerns, including, but not limited to: risk of abortion- pyrexia- fetal malformation-teratogenic effects – viraemia-risk of reassortment-short shelf life-revaccination and risk ofincomplete inactivation in killed vaccines.

The gap in the safety and immunity explains theneed for new promising candidates currently under development, such as subunit vaccines, virus vector and replicons (**Sabarish and Ikegami,2012*)(*Warimwe *et al.*,2016**). The most prominent among these candidates is a recombinant Capripoxvirus (CPV) Vaccine which was developed to protect against RVFV as well as against sheep poxvirus infection. Promising results have been reported in Pre-ClinicalStage trials including safety in pregnant ewes and offspring, stability of the vaccine and itspotential for DIVA(**Soi *et al.*,2010**).However, bringing of

RVF vaccine candidates to local markets besides the absence of validated serological test for DIVA remain the major challenges of RVF control(**Alhaj, 2016**).

1.12.RVF in Saudi Arabia

1.12.1.Epidemiological aspects of the 2000 outbreak

In 2000, there was a major (RVF) outbreak in south-west Saudi Arabia with high mortality and morbidity rates **(Balkhy and Memish,2003).**Jazan region-South west Saudi Arabia- has had the hardest hit by the disease in 2000. (65.6%) of animal cases occurred in Jazan,(26.9%) in Asir and (7.5%) in Alquenfeda. The infection rate was (23%, 8.7% and 2%) in Jazan, Asir and Alquenfeda respectively(**Alfadil *et al*.,2004)**.**Al-Afaleq *et al*.,(2003)** in a retrospective study it has proved that Saudi Arabia was free from RVF until 1995 and most probably before the 2000 epidemic(**figure 1.2**).

Figure 1.2: RVF habitat in Jazan region

Apparently, the virus seems to be introduced to Saudi Arabia during the religious festivals(Eid Aladha) through importation of live animals from African Horn countries, as long as, the virus isolated from the first patients during 2000 outbreak had an RNA sequence similar to the virus isolated in 1997-1998 East African outbreaks **(Davies, 2006*),(*Bird *et al*.,2007).**

This outbreak raised concernsabout the potential incidence and establishment of the disease in different environmental conditions and could affect areas haven't everexperienced thedisease before,since, the emergence of this virus in Arabian Peninsula was not as a result of genetic reassortment and the virus isolated in Saudi Arabia was found closely related to those associated with RVF epidemics in East Africa **(Fagbo, 2002), (Shoemaker *et al*.,2002).**

1.12.2.Control and prevention measures

The adverse effects of the disease and the serious socio-economic impacts obliged the relevant veterinary authorities to adopt an effective control program based on breaking the transmission cycle and raising herd immunity.Various control measures have been implemented in Jazan over the past sixteen-years including:Firstly, restriction of animal movement was implemented in the affected areas in Jazan, Tohamet Aseer, Tohamet MekkahandTohamet Al-bahah. Unvaccinated animals are not allowed to leave the outbreak zones.Secondly, vector control campaigns usingULV, fog and sprinkle sprayers in rural farms, cities and villages were routinely adopted. Thirdly, draining and filling of water swamps with soil were initiated as well as biological control and environmental management for immature stages. Fourthly, mosquito surveillanceand virus detection in mosquitoes by molecular techniques were routinely implemented. Finally, sustaining vaccination campaigns,regular examination of sentinel herds , serological examination of clandestine imports at Al-Twal quarantine station (at the border with Yemen), and targeted sero-surveillance during rainy seseons.

1.12.2.1VaccinationAgainst RVF

The inactivated vaccine was used during the first three weeks of the outbreak despite the risk of transmission within and between herds through the re-use of needles during vaccination campaign. This vaccinewas subsequently replaced with live attenuated vaccine (Smithburn strain) which has been used as the gold standard vaccine for several years and seems to play a significant role in control, as long as, no clinical disease in humans and animals has been reported yet,which reflects high efficiency performance in disease control and surveillance system (**Al haj *et al.*,2015**)(**Al Azraqi*et al*.,2013**).

1.12.2.2 Sentinel herds

Sentinel animals were about 275 animals at the same age and related to the local breeds. These animals were imported in 2004 from regions free from RFV infection and subjected to IgM and IgG antibodies tests against RVF disease before they were placed on eleven districts that were previously affected by 2000 outbreak: Alarda-Alhurath–Abuareesh-sabia- Almasarha- Bulgazi –Baish- Mahaeel- Mejardah- Mekhwa- quenfeda. Twenty-five animals were located on each site and had not been vaccinated yet**.**Consequently, these animals are highly susceptible to infection with RVFand could be used to investigate the potential existence of RVFV circulationduring inter-epizootic period (**Alhaj *et al.*,2015**).

1.12.2.3Land spraying

Outdoorland spraying with residual insecticides that is targeting adult mosquitoes is commonly used to control mosquito populationsin vegetation or resting sites such as animal sheltersat times relevant to the target mosquito activity, mainly 1-2 hours after sunset or 1-2 hours before sunrise. In Saudi Arabia, both of ULV spraying and thermal foggingequipment are usually mounted on ground vehicles (**Figure 1.3&Figure1.4**).

Figure 1.3: thermal fogging spraying over high dense vegetation

Figure 1.4: spraying of animal shelters in rural areas- Jazan region

1.12.2.4. Arial spraying

Arial spraying targeting adult and immature stageshas effectively reduced the insect populations over a large scale, notably, in areas not accessedby roads or ground vehicles such as dense vegetation, forested lands, valleys, streams, lakes and sewage stations. Both of helicopter and fixed wing aircrafts contribute importantlytovector control(**Figure 1.5**).

Figure 1.5: Arial spraying by fixed wind aircraft

1.12.2.5Biological Control

The numerous disadvantages of insecticides such as increasing resistance to commonly used pesticidesand the global growing concerns over the use of insecticides in the environments, have promoted the use of biological control and environmental management rather than chemical control. Biological control aimed to kill larvae without polluting or damaging the environment. An important advantage of larval control involves the use of living organism like bacteria, viruses, protozoa, fungi, plants, parasitic worms, predatory mosquito and larvivorous fish.

1.12.2.6 Environmental management

Environmental management is an effective approach in vector control to maintain permanent control of mosquito via altering or removing vector breeding sites, which can be obtained by covering water containers, removal of small used cans or tires, flushing steams, draining water to follow the natural flow, filling in ditches with soil or stones, subsoil drainage, growing Eucalyptus trees, expanded polystyrene beads and removing vegetation from water bodies(**Rozendaal, 1997**)(**Figure 1.6**).

Figure 1.6: drainage of stagnant water in Jazan region during rainy season

1.12.2.7Entomological Surveillance and intervention monitoring and evaluation

Mosquito surveillance commonly conducted before insecticides treatments to test the density of mosquitoes in breeding habitats and post treatments to evaluate the efficiency of spraying. A light co_2 bated trapsplaced overnight atdifferent locations where mosquito breeding sites are found. These traps are usually collected the following morning before sending to the laboratory (**Figure1.7**).

Figure 1.7: co^2 baited traps for mosquito surveillance in Jazan region

Chapter Two

Geospatial Techniques Application

2.1. Global Positioning System (GPS)

GPS is a satellite-based navigation system consisted of anetwork of 24 satellites, which placed into their orbit by the U.S. Department of Defense. It was first launched in1978 for military applications, then the system became available for civilian use whenever and wherever we need in the 1980. Most importantly, over a minimum of three satellites are required to constitute a signal for the GPS to calculate positions on the earth . Although, GPS satellites are powered by solar energy, they have backup batteries onboard to keep them running, when there's no solar power. Moreover, Small rocket boosters oneach satellite to keep it flying in the correct path.The GPS satellite weighs approximately 2,000 pounds and is about 17 feet across with the solar panels extended. However, the GPS structure consists of three segments :

(1) Twenty-four satellites placed into orbit.

(2) Portable mobile receiver.

(3) Base station receiver to carry out correction of the raw satellite signals(**Garmin, 2016**).

2.2.GIS – Definition, Functions and Applications

GIS is a computer based tool used to map, manage, organize, analyze, display, and model spatial information. It is nearly used in all disciplines that related to spatial data such as application in environmental assessment, analysis of natural hazards, site analysis for business and industry, criminal justice, real estate, location analysis, resource management, land use planning, global change, systems modeling and public health. One of the GIS's other function is to provide an ideal platform for the convergence of disease-specific information and their analysis in relation to population settlement, surrounding social and health services and natural environment. Moreover, it is highly suitable for mapping epidemiological data, revealing trends and interrelationships that otherwise would be more difficult to discover(**Bhatt and Joshi, 2012).**

2.2.1. Application of GIS in Epidemiology and Public Health

The application of GIS in veterinary activities that are mostly spatial in nature has been developed over the last decade. It is highly suitable for mapping spatial aspects of diseases, analyzing epidemiological data over a large spatial scale, revealing trends and visualizing problems to enhance decision making and improve the intervention efforts(**Bhatt and Joshi,2012**).

GIS technology is not only considered as one of the most important information systems for public health researches and epidemiology, but alsofor prediction and early detection of infectious disease. Many advantages have been presented by using GIS technology in epidemiology including studying infectious diseases, mapping point locations of cases, creating buffer zones, detecting rates and clusters(**Saxena *et al*.,2010**).Another advantage of GIS is health planning of primary care allocation whichis based on geographical locations, distances and population density(**Moore and Carpenter,1999**). Most importantly, GISs can be applied for monitoring the spatial extent and spreading pattern of the disease, understanding disease dynamics and identifying critical intervention area **(Bouwmeester *et al*.,2010).**

In epidemiological studies, GIS has offered a more powerful tools and great ability to strengthen the capacity of epidemiological analysis, linking databases with thematic maps, revealing trends, finding associations between location, disease and environment along with prediction of a newly introduced disease (**Najafabadi,2009**). Several infectious diseases have currently been analyzed and predicted by using GIS technology. **Zou *et al*.,(2007**) presented a useful method by using a spatially explicit degree-day model, for estimating West Nile Virus in a large spatial scale based on vector population and temperatures information. In Senegal, **Soti *et al*.,(2013*)*** shed a light on the potential of very high spatial resolution remote sensing data for identifying environmental risk factors

and extracting mosquito favorable biotopes to identify risk areas of RVF transmission at local scale when the statistical analysis showed a strong correlation between RVF incidences and the vegetation density index (VDI). At the same study area, **Vignolles *et al.,(*2009**) established a new approach to identify risk zones, based on analysis of variables associated with Rift Valley Fever such as zones potentially occupied by mosquitoes, rainfall events and pond dynamics, and susceptible host. This new model may contribute to implementation of Early Warning System.

Early detection of diseases is an important step toward effective intervention strategies that strived to lessen the duration and severity of outbreaks. Most infectious diseases are strongly linked to climate which constrains the range of infectious diseases and affects the timing, distribution and intensity or severity of outbreaks(**Epstein,2001**). Accordingly, understanding the interaction between climate condition, vectors and infectious diseases could lead to establishing models that are capableto forecast the time and location, which in turn will lead to improving the levels of preparedness before the disease is out of control (**WHO, 2004**).

Several outbreaks in Africa, most notably in the horn of Africa demonstrated that using satellite measurements of global and regional elevated rainfall, elevated sea surfacetemperatures and satellite derived normalized difference vegetation index have been proved

highly beneficial in predicting outbreaks of RVF with lead-time of 2-4 months (**Anyamba *et al*.,2010**). Currently, several methodologies are available and widely used for the prediction of infectious diseases outbreaks including risk factor analysis, risk modeling and dynamic modeling (**Woolhouse, 2011**). Such prospectivedisease risk mapping models using climate data could predict areas where outbreaks in animals and humans were expected, in order improve outbreak response and intervention activities (**Anyamba *et al*.,2009**).

2.2.2.GIS and Spatial Analysis:

Spatial Analysis is defined as a general ability to manipulate spatial data into different forms and extract additional meaning as a result. It is more concerned with predictionto gain insight into patterns and possible relationships between patterns and other features that maynot be evident from traditional databases. While, statistical spatial analysis encompasses a range of methods to address different spatial problems such as image enhancement, interpolation of spatio-temoral clustering of diseases and the modeling of socio economic trends (**Fotheringham and Rogerson, 2013**).

In fact, spatial analysis is usually concerned with questions that are not directly answered by looking at data, but refers to hypothetical processes that generates the observed data. Although, such processes are often challenging, they are necessary when we try to draw conclusions about questions that interest us. GIS data are usually stored in more than one layer to cope with technical problems due to handling very large amount of data at once, such methodis named data integration(**Bivand *et al*., 2013**).

2.2.3. Application of Remote Sensing to Vector Habitats

A number of civilian satellites remote sensing systems operated by the U.S., France, Japan, Russia, India, and the European Space Agency (ESA), provided regular coverage over much of the earth's surface. The launch of ERTS-1(Earth Resources Technology Satellite 1) in 1972 provided the first opportunity to acquire global remote sensing data on a regular basis. In 1980, French started developing a series of remote sensing satellites, the first in this series was spot1. In 1991, the European Space Agency, launched the European Remote Sensing satellite (ERS-1). Following that, the Japanese Earth Resources Satellite (JERS-1), was launched in February 1992 (**Washino and Wood,1993**).

The application of remote sensing and GIS in monitoring environmental factors that influence the pattern and distribution of vector borne diseases was successfully investigated

in several studies. Based on an average adult mosquito flight range of 2 km, GIS was used to create buffer zones around breeding habitats describing areas at risk from mosquito in Wadi El Natroun, Egypt. The obtained results provided a new basis for directing the control of mosquito vectors as they provide health authorities with precise maps of mosquito breeding habitats (**Hassan and Onsi, 2004**).

Remotely sensed data extracted from QuickBird and LANDSAT satellites could potentially be used to estimate the distribution of immature and adult mosquito populations. The classification of LANDSAT imagery permitted good separation between land-use classes, therefore has enabled the distribution of mosquitoes in the republic of Korea**(Sithiprasasna *et al*.,2005).** The surface slope and wetness indices around three malaria-endemic villages inThailandwere modeled by **Sithiprasasna *et al*.,(2003)**,to identify the extent and spatial pattern of potential mosquito breeding habitats by digitizing base topographical maps of the study site and overlaying them with coordinates for each larval habitat. Such model possibly forecasting the distributions of mosquitoes and enabling public health agencies to institute control measures effectively.

Soti *et al*., (2013*)*highlighted the potential ofvery high spatial resolution remote sensing images - (2.4 m resolution) provided by the Quickbird sensor- to produce a detailed land-cover map of the study area for identifying environmental risk factors and mapping RVF risk areas around Barkedji village, Ferlo region, Senegalbased on knowledge of vector and disease ecology. Additionally, **Nihei *et al*.,(2002)**used 1997satellite image datatoexamine the relationship betweennormalized difference vegetation index(NDVI) values and malaria incidence in order toestimate the distribution of malaria in Mekong region in the Indochina Peninsula.The monthly NDVI maps were overlaid with malaria distribution maps that included reported cases ofmalaria incidenceand mortality for the year 1997 and 1998. Final results indicated that maps with NDVI values of (+0.3 and +0.4)strongly matched the distribution of falciparum malaria.

2.2.4. Common methodology to Identify Vector Borne Disease

The common GIS methodology to identify vector borne disease depends on:

1. The data on different types of vectors causing infectious diseases, their survival conditions and other data relevant to the vectors are collected.
2. The distribution of the population in a given region is gathered and sorted according to age group.
3. The map of the given region is obtained from the respective source. All the features in the map are digitized into their respective themes.
4. The vector breeding sites in that particular region is identified using suitable techniques.
5. The landscape composition and the population distribution are digitized on the map.
6. Buffers are created for the given population categorizing them into commercial area, institutes, and residential areas. Depending on the flight range of different vectors, suitable buffers are created from the vector breeding sites taking into consideration all the environmental and seasonal factors.
7. All these buffers are analyzed and using suitable operations such as union, intersection, overlay, network the vulnerable areas and the vulnerable group of population are assessed.
8. Depending on the results, suitable preventive and control measures are taken. Identifying vectors breeding sites, the distribution of the population, landscape composition, and creating buffered zones according to vectors flight range and air flow direction to assess the vulnerable population groups prone to the disease of interest (**Gupta and Shriram,2004**).

2.2.5.Epidemiological Models and Early Warning System

Modeling is a way to mathematically replicate and approximate the actions of complex systems to better understand their current behavior and predict future activity. Such ability could be vital in anticipating the spread of disease and allowing officials to take action in time to curb outbreaks before they get a chance to run wild.Epidemiological
models aimed to predict future outbreaks through disease risk factors and understanding the transmission pattern between animals, humans and vectors.The output of these models can

help better understand the dynamics of infectious diseases and would increasingly guide control and surveillance programs with more confidence and effectiveness(**ASU,2016**).

Mathematical models for mapping dengue fever including but not limited to the AutoRegressive Integrated Moving Average (ARIMA) and Seasonal AutoRegressive Integrated Moving Average (SARIMA) models, which have the ability to cope with stochastic dependence of consecutive data. Another approach to predicting the spatial dynamics of both human dengue cases in relation to vector presence was presented through ecological niche modeling using GARP (Genetic Algorithm for Rule-set Prediction). The objectives of these models are that they were either used as a retrospective and validating method,or as an early warning tool to predict potential epidemics (**Raclo*et al*.,2012**).**Manyong *et al*.,(2008)**created, a GIS model in the Great Lakes region to study the spatial extent and the geographic distributionofBanana Xanthomonas wilt (BXW), as well as,fighting the spread of pests, based on reported BXW incidence from 2001 to 2007 and environmental data.

In Sinnar State, Sudan, high risk zones for RVF were investigated by using remote sensing and GIS techniques. Remote Sensing data and rainfall patterns were integratedin a GISwith other information including, soil type, water body, DEM (Digital ElevationModel), and animal routes; these data were then analyzed using Spatial Analysis tools. The studyconcluded that, the risk of RVF increases proportionally with the amount ofrainfall and vegetation cover (high NDVI values),which both simultaneously provided suitable conditions for vectorsand considered as a good indicators for RVF epizootics in Sudan(**Ahmed *et al*., 2015**).

A Semi-Quantitative Risk Modeling and Statistical Risk Modeling was used to develop an RVF risk map for Kenya by using surveillance records collected between 1951 and 2007.The final output was a RVF risk map that classified 101 of 391 divisions (26%) in 21 districts as high risk, and 100 of 391 divisions (26%) located in 35 districts as medium risk and 190 divisions (48%) as low risk. The risk of RVF was positively

associated with Normalized Difference Vegetation Index (NDVI), low altitude below 1000m and high precipitation in areas with solonertz, luvisolsand vertisols soil types ($p < 0.05$)(**Munyua *et al.*,2016)**.

Likewise, inSpain,a multiple criteria decision making model,was established to identify areas and time periods with highest suitability for RVF outbreak occurrencefor improving the early detection and rapid response of the disease into free countries. Methods and results used in this model may be useful to target risk-based surveillance strategies and control activities **(Sánchez *et al.*,2013).**

2.3. Accurate Definition of High Risk Area

According to **FAO,(2003),** the accurate definition of areas that are likely to become infectedwith RVF should be based on the following criteria :-

- Evaluation of satellite information such as weather, vegetation growth
- Demarcation of mosquito breeding habitats
- Defining the range ofprimary and secondary RVF vector species and likely density.
- Distribution and density of susceptible livestock populations.
- Historical information on the virus distribution andepidemic behavior during previous RVF outbreaks.
- Definition of potential extension zones for RVF in the countrybased upon the ecological zones and livestock populations.
- Estimation of the likely duration period for RVF virus propagationbased upon historical ecological and climatic information.

The previous information should be created in a form of GIS individual layers which can be combined with other features to form a single map of potential epizootic area.

Chapter Three

Materials and Methods

3.1. Study Area and Population

Jazan region is located on the farthest south-west Saudi Arabia between longitudes 41ºE and 43º E and latitudes 16ºN and 18ºN, near the Yemeni borders which represent the southern and eastern borders. The Red Sea borders the region from the west for a distance of (330) Km2 along the sea coast, while Asir region from the north. The region covers an area of 40.457 KM^2 and it is divided into 13 governorates and 31centres. The terrain of the region variesand consists of mountain, costal and fertile plains (**Emirate of Jazan province,2016**).Interestingly,the region is considered as one of the most densely populated regions in Saudi Arabia, the General Authority for Statistics-Saudi Arabia, estimated that in 2010 there were 1.374.845person in Jazan region(**GAS,2016**).

Several seasonal valleys extend from mountains constituting alluvial flood plains. The methods used for the utilization of the spate flow in valleys, such as making changes in Wadi system by orienting the water flow to field units through channel systems, have complicated the situation, resulting in many large and small water pools **(Davies and Martin, 2003**). The existence of both ecological diversity pattern and different types of vegetation, listed the region among the richest areas in Saudi Arabia with animal biodiversity (**Masood,2012).**While the average temperature throughout the year is 30°C,thehighest oneon averagewasobserved in June at around 33.6 °Cand the lowest degreewas reported in January at around 25.7°C(**Climate data org, 2016**). The considerable amounts of rainfall, besides the hot humid climate conditions and fields that are irrigated from Wadies, support both of the agricultural and animal production activitieswhicheventually provide an ideal habitats for RVF vectors.

3.2. Mosquito Surveillance

A targeted vector surveillance was performed in Jazan region from 18 October 2015 to 4 Sept 2016, to examine the distribution and abundance of potential arthropods vectors, at genus level. 21 light traps were set at 375 different locations in six districts with habitats constitute a favorable ecosystem for RVFV, including AL-ardah, Ahed Al-msarha, Sabia, Baish,Balgazi, and Abuareesh). The trap sites were selected on the basis of perceived risk of disease introduction, areas where confirmed or suspected RVF cases were previously reported, outdoor shelters and wild vegetation as well as in the vicinity of Wadies, ponds, dams and sewerage stations. A CO_2 (dry ice)- baited light traps were placed outdoor in the evening approximately one hour before sunset and collected the following morning (from 6:pm to 6:am). Adult mosquito samples were sent to Jazan veterinary laboratory where they were identified morphologically at genus level with a digital microscope by using mosquito keys**(Means, 1979).** All samples were labeled based on genus, sex, GPS location and date. Subsequently, they were stored at -80^{o}C and subjected to virus detection by PCR.

3.2.1. Data Analysis

3.2.1.1 Relative Abundance (RA %):

The dominance of the mosquito species at each site was estimated by the relative abundance (RA%). This was expressed by the ratio between number of specimens of a species and the total number of specimens of all mosquito species caught in the site ×100 **(Aïssaoui and Boudjelida, 2017).**

3.2.1.2. Pattern of occurrence (C%):

The distribution of mosquito species was estimated using the pattern of occurrence (C%) i.e. the ratio between the number of sites positive for the occurrence of mosquitoes and the total number of sites studied**(Rydzanicz and Lonc,2003*).***

3.2.2. Molecular detection of RVFV:

RT-PCR test was conducted for the detection of the virus in mosquitoes as described previously by**Sall *et al*.,(2001).** A total number of 16,300 adult female mosquitoes were pooled in groups of 50 individual mosquitoes at collection site. 326 specimens were processed to obtain a supernatant fluid which was tested by RT-PCR to identify the presence of RVF viral RNA. Viral RNA was extracted from mosquito homogenates using Trizol-LS reagent according to the manufacturer's instructions. The final RNA pellet was re-suspended in 12 µL of nuclease-free water and then stored on ice or frozen at −80°C. The one-step RT-PCR was performed using the light Cycler RNA Amplification Kit, SYBR Green1, and the light Cycler instrument(ROCHE). The RNA was converted into complementary deoxyribonucleic acid (cDNA). ThecDNA segment of the RVFV, and the live attenuated RVF Smithburn strain vaccine Registered NO. G 0124 were used as a positive control.

3.3.Geospatial Analysis

3.3.1. Software

Arc GIS desktop 10.2 from (ESRI Inc., Redlands, CA) company wasused for collecting, displaying, analyzing data and modeling. All datasets were imported into the software as raster or shape-file formats and re-projected to datum WGS1984.

3.3.2.Data Sourcesand collection methods

The GIS data setsused in this study involve the following data : Gizan boundary ,districts,water drains and dams,locations of mosquito breeding sites,vector density, vector distribution,human distribution, animal population,animal and human reported cases,monthly average rainfall,sero-surveillance positive cases,monthly average NDVI

values andDEM(**table 3.1**). These datawere collected by field observations, satellite images and veterinary records that belong to the General Administration for Agricultural Affairs in Jazan-Ministry of Environment, Water and Agriculture-KSA.The outbreak data set of the year 2000 and the sero-surveillance data were obtained from veterinary records. Vector distribution and mosquito density data were investigatedthrougha field survey. The field surveyed data were collected with GPS coordinates before geocoded into the GISbased on geographic latitude and longitude. Theclimate parametersand vegetation images, were downloadedfree of charge from LANDSAT(**Linthicum *et al*.,1987**).

Table 3.1. RVF Data Sources

Object	Source of data
Gizan boundary, administrative districts, Water drains, dams and population	Diva-GIS spatial database (www.diva-gis.org/Data)
Livestock distribution	Ministry of Environment, Water and Agriculture-KSA
Human distribution	General Authority for Statistics http://www.stats.gov.sa/en/node
Vector Density	Field observations
Vector Distribution	Field observations
Vector breeding sites	Field observations
Rainfall data	Ministry of Environment, water and Agriculture-KSA
NDVI	Satellite images (Landsat)
DEM	Shuttle Radar Topography Mission90
Animal and human reported cases	Ministry of Environment, Water and Agriculture-KSA
Sero-surveillance positive cases	Ministry of Environment, Water and Agriculture-KSA

3.3.3. Database Component

The current GIS database is grouped into foursets ofvariablesserving as potential indictors for RVF occurrence. These variables are including: environmental risk factors variables, vector variables, animal risk factor variables and human distribution variable(**Table 3.2**).

Table 3.2. database components

	Variable	Description
1	**Environmental and climatic Variables**	
	Rainfall Data	Average monthly rainfall expressed in millimeters for the period 2005-2015
	NDVI	NDVI average values for the period 1987-20150
	DEM	Contours line were used to predict water accumulation
2	**Vector Variables**	
	Breeding habitats	Water bodies within the study area (Water pools, , valleys, sewage stations, dams)
	Vector Density	The average number of mosquitoes in trap per site
	Vector Distribution Data	Location of mosquito by species, based on geographic latitude and longitude
3	**Animal Risk Factors Variables**	
	Livestock Distribution	Visualization of high density areas.
	Reported cases in 2000 outbreak	Animal and Human reported cases in 2000
	Positive sero-surveillance cases	Recent and previous confirmed positive cases during sero-surveillance
	Positive cases in Sentinel Herds	Reported cases in Sentinel Herd from 2004-2017
4	**Distribution of Human Population**	Visualization of cities with more than 4000 people

3.3.3.1.Environmental and Climatic Variables

Environmental and Climatic Variables were used to identify high risk zones as theyare often related to disease incidence andprofoundly influence the survival of vectors and

virus infectivity as well(**Elfadil *et al*., 2006)**.Thesevariablesare controlled by several factors includingrainfall, normalized difference vegetation indexand DEM. The elevation data were used to predict water accumulation in low lying areasthatare associated with aquatic habitats**(Wasilewski and Chormański, 2009**). The free available NDVI values from1987 to 2010, were downloaded from the LANDSATsatellite to calculate the long term mean value. Themonthly mean rainfall was extracted from a long term dataset of rainfall during the period between July 2000andOctober 2015,these data were obtained from (http://app.mowe.gov.sa/DailyRainsNews/Rain_Dams.aspx)

3.3.3.2.Vector Variables

Several factors contribute to the emergence of arboviruses, includingproximity to breeding habitats, vector density, proportion of infectious mosquitoesand biting rates **(Kalluri *et al*.,2007**). In the current study we measuredvector density as the mean number of mosquito in each trap site, while vector distribution wasperfectly represented by longitude and latitude coordinates for each mosquito species.

3.3.3.3.Animal Risk Factor Variables

This section includes the following parameters :animal and human reported cases during the 2000 outbreak(**Table 3.3**) the distribution of animal population (**Table 3.4**),as well as sero-surveillance data and reported cases in Sentinel Herds from 2004-2017(**Table 3.5**).

Table 3.3. Animal and human reported cases in the 2000 outbreak

SN	Location	Number of Animal cases	Number of Human cases	Lat (N)	Lon(E)
1	Dayhamah	4	2	16.53221	42.79784
2	Altwal	7	3	16.52875	42.9683
3	Bathan	10	5	17.03058	43.05105
4	Almowsam	5	0	16.43674	42.82814
5	Algofol	2	1	16.6732	43.0791
6	Samtah	11	5	16.59449	42.93817
7	Alkhobah	41	12	16.78284	43.21557
8	Al-msarha	26	5	16.71019	42.95594
9	Wadi Jazan	2	0	17.06712	43.17194
10	Alsalb	65	9	16.8719	43.1203
11	Alardah	47	24	17.35284	43.07696
12	Abuareesh	12	3	17.00787	42.83217
13	Damad	17	0	17.10773	42.77629
14	Alhomairah	173	1	17.43557	42.88462
15	Wadi baish	10	1	17.38242	42.55728
16	Bulgazi	35	12	17.23656	43.01757
17	Sabia	45	2	17.15112	42.64493
18	Bany Malik	27	1	17.33917	43.13232
19	Alshigairy	28	1	17.13374	42.82676
20	Faifah	48	0	17.26705	43.11069
21	Alaidabi	48	2	17.23771	42.941
22	Alaalia	1	1	17.26919	42.53842
23	AlKudmi	42	2	17.26914	42.76685
24	Baish	25	1	17.33393	42.5728
25	Alhago	2	1	17.51294	42.69733
26	Itwad	1	0	17.62373	42.23179
27	Maslyah	37	0	17.46104	42.55691
28	Haroob	162	19	17.43557	42.88461
29	Wadi qura	5	0	17.33397	42.58
30	Aldarb	13	0	17.7343	42.24071
31	Alraith	39	6	17.61621	42.82574

Table 3.4. Animal distribution in Jazan region

Province	Sheep	Goat	Cattle	Camels	Horses	Total	lat (N)	lon(E)
Gizan	135000	120000	350	6000	50	261400	16.93038	42.61185
Al-ardha	292659	358911	7588	2855	12	662025	17.03955	43.04744
Almsarha	425018	258811	16781	8409	45	709064	16.70756	42.95071
Baish	89100	197900	25247	20410	43	332700	17.38078	42.54524
Alraith	13500	94000	3790	10225	0	121515	17.60934	42.83913
Abuareesh	132716	136500	27000	1300	58	297574	16.96896	42.83072
Alshigaig	60000	95000	700	3000	1	158701	17.71991	42.23969
Al-hurth	123000	82000	3500	1100	0	209600	16.78466	43.18228
Balgazi	130200	311850	2000	1865	0	445915	17.23984	43.02521
Sabia	343000	430200	11935	3315	70	788520	17.16146	42.64652

Table 3.5. positive sero-surveillance cases

SN	Location	District	Date	Number		Lat (N)	Lon(E)
1	Alhudon	Baish	16/8/1427	1	farmer	17.40648	42.57082
2	Qilwah	Qilwah	19/8/1427	1	farmer	19.94713	41.2501
3	Mahayel Aseer		15/8/1428	3	sentinel herd	18.5461	42.05257
4	Alrakobah	Al-msarha	22/8/1428	2	farmer	16.62014	42.96662
5	Aledabi	Bulgazi	1429	1	sentinel herd	17.23755	42.93899
6	Alkhobah	Alhurth	1429	3	sentinel herd	16.78264	43.21584
7	Alkhadrah	Baish	1429	2	sentinel herd	17.27968	42.53743
8	AlKudmi	sabia	1429	3	sentinel herd	17.26939	42.7672
9	Qana Albahar	Gnah Albahar	10/11/1429	1	farmer	18.34084	41.92726
10	Alganborah	Almsarha	1431	3	farmer	16.41402	42.88919
11	Alrakobah	Almsarha	5/1431	3	sentinel herd	16.78264	43.21584
12	Almoger	Abuareesh	1/4/1432	1	sentinel herd	17.01603	42.91744
13	Aldager	Alardah	1432	3	farmer	17.03888	43.09595
14	Almkhwah	Almkhwah	1434	2	farmer	19.80167	41.42756
15	Albahteet	Alhurth	5/8/1435	2	sentinel herd	16.78492	43.18661
16	Khabt Albager	Alardah	26/11/1435	1	sentinel herd	17.02163	43.1054
17	Almoger	Abuareesh	14/11/1435	1	sentinel herd	17.01603	42.91744
18	Mahayel Aseer	**Mhayel Aseer**	17/9/1435	1	sentinel herd	18.5461	42.05257
19	Almoger	Abuareesh	14/11/1436	2	sentinel herd	17.01603	42.91744
20	Amaldood	Alardah	8/7/1436	1	mosquito	17.06295	43.03815
21	Wadu shahdan	sabia	11/2/1431	5	mosquito	17.26914	42.76685
22	Khabt Albager	Alardah	19/1/1432	1	mosquito	17.02163	43.1054
23	Alshigairy	sabia	9/1/1432	1	mosquito	17.12996	42.82771

3.3.3.4. Human distribution

The spatial distribution of human population within temporary ponds, low laying areas and flooded areas that are potential vector breeding sites increases the likelihood of RVF transmission.In this study, we mapped the distribution of human in cities with a population more than 4000 people (**Table 3.6**).

Table 3.6. Human distribution in Jazan Region

City	Total population	Lat (N)	Lon (E)
Gizan	127743	16.93038	42.61185
Al-ardha	6947	17.03955	43.04744
Almsarha	25007	16.70756	42.95071
Baish	30835	17.38078	42.54524
Alraith	4000	17.60934	42.83913
Abuareesh	61047	16.96896	42.83072
Alshigaig	4000	17.71991	42.23969
Al-hurth	7091	16.76887	43.1373
Balgazi	4000	17.23984	43.02521
Sabia	63143	17.16146	42.64652
Samtah	32458	16.59835	42.94761
Damad	24056	17.10666	42.77741
Al-dayer	15103	17.33982	43.13215
Al-dhabya	11697	17.11355	42.66248
Al-Durb	8878	17.74116	42.28225
Algurphy	8719	16.99121	42.77612
Alalya- Alkhadra	7678	17.27172	42.53906
Algaradya	8488	16.58149	42.91534
Almadaya	7752	16.76854	42.73475
Alaydabi	7672	17.23385	42.94203
Hakmah	7656	17.00803	42.83105
Almatan	7652	17.42615	42.54618

Altoal	7550	16.52842	42.97216
Alshigary	7238	17.13422	42.82766
Almobarakah	5081	16.53514	4294251
Maslya	6776	17.4612	42.55777
Alhusainy	6230	17.15276	42.68445
Abu-alsala	5931	17.23984	42.60661
Algadya	5867	16.79533	42.99267
Mozherah	5849	16.82623	42.73552
Iskan Alhasamah	5000	16.82984	42.95894
Abu-alsadad	5536	17.72726	42.22274
Al-lagyah	5096	16.65675	43.03919
Al-rakobah	5091	16.62227	42.96787
Ramadah	5000	16.6891	42.99104

3.3.4.GIS Mapping and Analysis Criteria:

Data of interest were manipulated to meet the following criteria:

- Average monthly rainfall during 2000-2015.
- Average NDVI values during the period (1987 - 2010).
- Mean value of mosquito number per trap site.
- Distribution of *Aedes.spp*.
- Locations of water bodies (ponds-valleys-sewage sites-dams-temporal ponds) based on geographic latitude and longitude.
- Locations of animal and human reported cases during 2000 outbreak.
- Distribution of livestock.
- Distribution of human populations in cities **(**over 5000 persons**)**

All datasetswere then prepared in Microsoft Excel files and were converted to Esri -shape files before integrated in Arc GIS 10.2.Based on the above mentionedcriteria, multipleGIS layers were created according to GPS surveyed coordinates and thegeoreferenced remote sensing data, to be used in the geo-spatial analysis and statistical modeling (**Table 3.7**) :

Table 3.7. GIS layers

GIS layers	
layersbased on GPS	**Remote sensing layers**
Human distribution layer.	
Monthly mean rainfall layer.	Mean NDVI value
Animal and human reported cases layer.	
Livestock distribution layer.	
vector distribution layer	Dem layer
Vector density layer.	
Positive cases in Sentinel animals and within sero-surveillance	
Temporary ponds, valleys and dams layer	

3.3.5. Geo-processing Tools

Different GIS operations and geo-processing tools, including overlay analysis, buffer analysis, network analysis, intersection analysis, distance calculation queryand digital elevation model, were considered in analysis for a betterunderstanding of the disease incidence (**Saxena *et al.*,2009**).In this study,the researcher combined multiple reclassified individual layers of NDVI, DEM, average rainfall, animal and human distribution and mosquito breeding sites buffer zone, into a single map to create one layer whichrepresents the high risk areas that most likely prone to RVFoutbreaks.

3.3.5.1.Overlay and Combining

Multiple layers were overlaid to study the spatial distributionof RVF and define zones where the disease is most likely to be endemic. Mosquito density layer was created and combined with human population layer. Moreover, DEM layer was processedby using Arch hydro Extension to identify catchment area,this layer was overlaid with RVF reported cases during the 2000 outbreak to investigate the effect of altitude upon RVF Incidence.

3.3.5.2.Buffer zone Analysis

1.5 Km buffer were created around the overlaid layers of mosquito breeding sites, mosquito density and human distribution layerto identify human populations who are at risk of mosquito bites(**Sayeedet al., 1999**).

3.3.5.3.Kriging

Kriging is used to interpolate the spatial distribution of Aedes mosquito in the region and demonstrate clustering.Choropleth maps were created to display monthly mean rainfall and mosquito density by colors**.**

3.3.5.4. The inverse distance weighted tool (IDW)

The inverse distance weighted tool was used to create surface showing the distances from each cell of the surface to the nearest breading siteto estimate mosquito density at unsampled locations(**Lu and Wong, 2008**).

3.3.5.5.Statistical Risk Model

High-risk areas can be identified by using GIS software and remote sensing technologies that would otherwise be difficult to determine using traditional methods**(Ceccato*et al.*,2017**). In this study, we developed a new risk model to identify high-risk area for RVF in Jazan region based on thespatial relationship between the disease and associated risk factor variables. The data involved inconstructing the model were used as
criteria (i.e. layers) to be input to the model processes**.** The layers were grouped as:

1. Environmental criteria i.e. 1) average NDVI, 2) rainfall, and 3) digital elevation model layers.
2. Vector criteria i.e. 4) mosquito breeding sites, 5) Aedes density, and 6) mosquito density
3. Human criteria i.e. 7) human population distribution, and 8) RVF positive cases among the residents of the study area.
4. Animal criteria i.e. 9)animal population distribution, 10) RVF positive cases among the animals living in the study area, and 11)positive sero-surveillance layers.

All the above layers were classified into 10 classes by the software tool layer properties. First, the WOT was used to overlay the individual layers of each group separately **Figure(3.1)**.then, the groups of variables were overlaid using the group weights as shown in **Figure(3**.1).

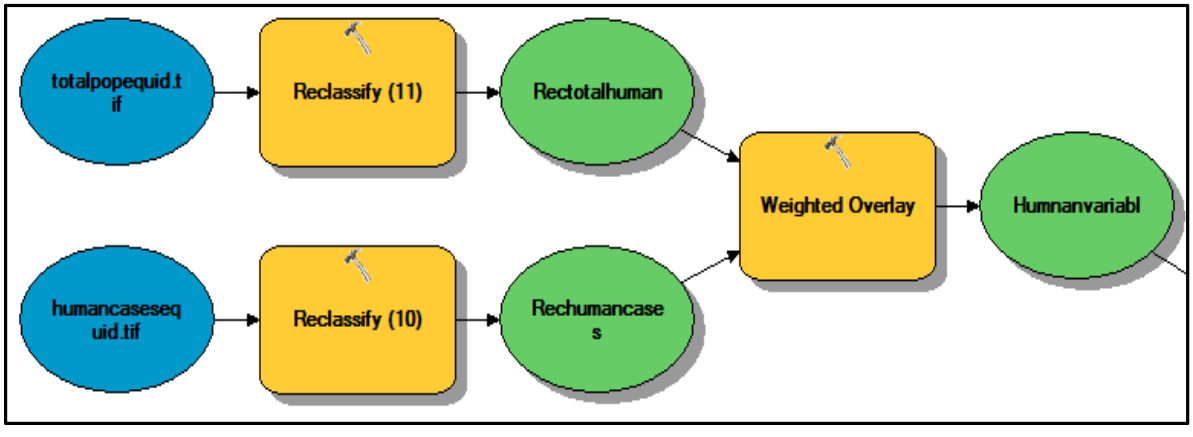


Figure (3.1): Sample of the process for weighted overlay

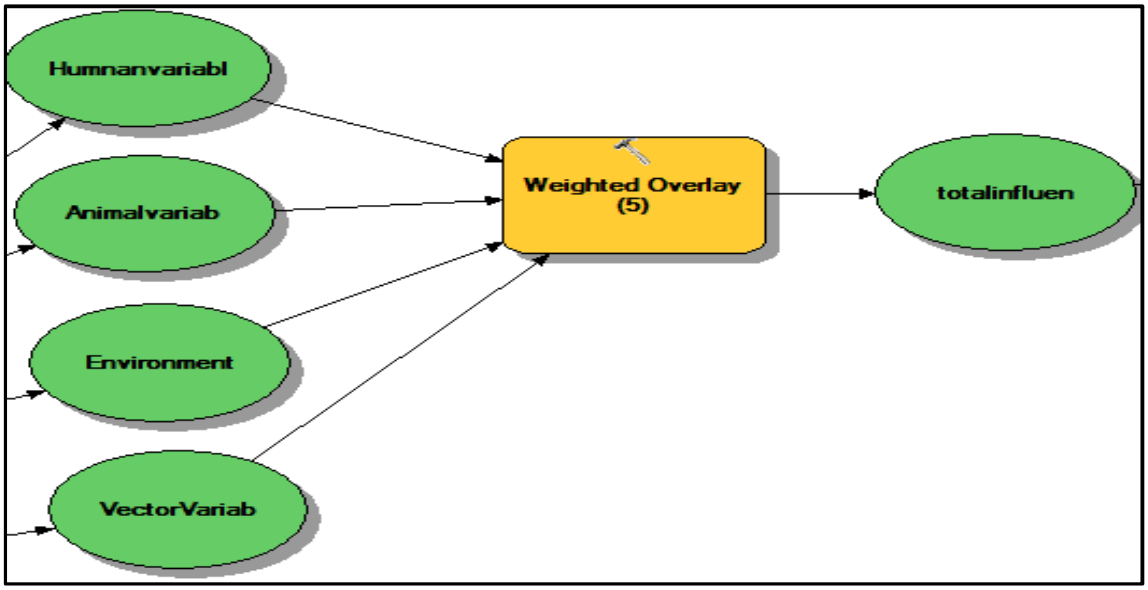


Figure (3.2): the process of the weighted overlay of the 4 groups

Chapter Four

Results

The current study investigatedthe abundance andthe geographic distribution of potential vectors of RVFVduring inter-epizootic period in Jazan region as well as some spatial aspects that influence the epidemiology of RVF tostrengthendisease surveillance and response system effectively. The study further investigted locations where humans are potentially exposed to RVF and identified thehot spot and cold spot points of vector density. Furthermore, the researcher studied the distribution of animals, the distribution of rainfall and reported cases of RVF in human and animal during the 2000 outbreak. Finally, and most importantly, weconstructed statistical spatial risk model to identify high-risk zones that could be targeted with preventive interventions.

4.1.Abundance and distribution of potential vectors for RVFV

A total of 128,190 adult mosquitoes, 3,229 *Phlebotomine sandflyies* and 2,018 *Culicoides* were collected in 21 light traps at 375 sites belonging to six districts which include Al-ardah, Abuareesh, Sabia, Almsarha, Bulgazi and Baish. Of 375 sites, Aedes, Culex, Sandfly, Culicodies were collected from (84,344,59,24) sites respectively.

The results obtained from this study revealed that a significant variation in mosquito density was found within districts. Among the collected mosquitoes *Culex* was more abundant and present in most sites(91.73%), with RA% ranged from 98.48% in Baish and 91.00% in Bulgazi. In contrast, Aedes was recorded in 84 locations, and 29 of these sites (32.8%) had only Aedes. In addition, itwas found more distributed in Sabia(2.46%), but less common in Baish(0.73%) .

A total of 3,229 *Phlebotomus* and 2,018 *Culicoides* were collected during the study period . The highest *phlebotomus* abundance was(5.6%)at Bulgazi, followed by (4.36%) in

Almsarha and (3.89%) in Abuareesh. Moreover,they were widely distributed in altitudes between 24-760 meter above sea level. Concerning *Culicoides* - an important BlueTongue (BT) vector in Jazan region - were distributed abundantly in Almsarha (3.13%) and abuareesh (2.18%) but scarce in Sabia(0.02%) and Alardah(.05%), while not reported in Baish(**Table 4.1**).

Table (4.1): Abundance of mosquito in different districts

Districts	Relative abundance (RA%)			
	Culex	***Aedes***	***Phlebotomus***	***Culicoidies***
Al-ardah	97.27	2.0	0.22	0.51
Abuareesh	93.27	0.73	3.89	2.18
Al-msarhah	91.16	1.35	4.36	3.13
Baish	98.48	0.73	0.79	0
Sabia	95.18	2.46	2.34	0.02
Bulgazi	91.00	1.96	5.6	1.51

The pattern of occurrence was estimated as constant in *Culex* with value of (91.73%) followed by infrequent in *Aedes* (22.13%) and sporadic in both of *phlebotmus* (15.73%) and *Culicoides*(6.4%) (**Table 4.2**).

Table (4.2): Pattern of occurrence of mosquito genera in Jazan region

Mosquito Genera	(C%)	Distribution Pattern
Culex	91.73	Constant
Aedes	22.4	Infrequent
Phlebotomus	15.73	Sporadic
Culicoides	6.4	Sporadic

Most importantly, all samples tested by RT-PCR were reported as negative for RVFV (**Table 4.3**).

Table (4.3) : The Results of PCR Tests

Districts	Alardah	Abuareesh	Al-msarhah	Baish	Sabia	Bulgazi
Number of Samples	134	84	61	3	11	33
Positve Samples	-	-	-	-	-	-

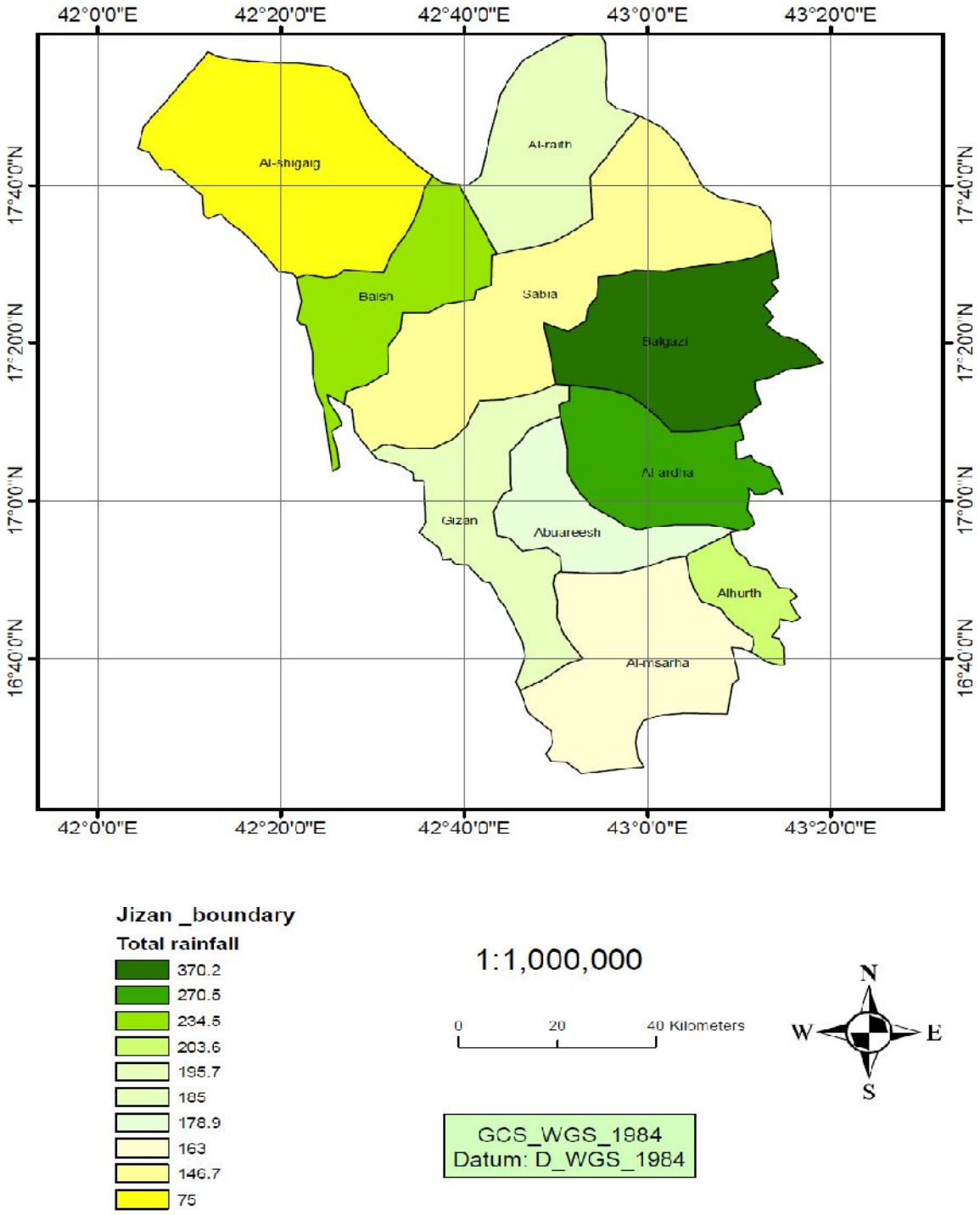
4.2. Geospatial Analysis

High-risk area for RVF were identified based on the spatial relationship between the disease and associated risk factor variables which including environmental risk factors variables, vector variables, animal risk factor variables and human distribution variable. However, the finalresultscan be presented as follows:

4.2.1. Environmental Risk Factor Variables:

The rainfall distribution patterns and amounts in Jazan region were studied for the period between 2000 -2015. Results indicated that the mean annual precipitation is theheaviest over Bulgazi, Al-ardah,Baish and Al-hurth as high as 370.2 mm, 270.2mm 234.5mm and 203.6 mm respectively **Figure (4.1**).

Additionally,NDVI images were extracted from landsatfor the years (1987, 2001, 2007, and 2010). The average NDVI for the study area was calculated using Spatial Analyst Tools – Raster Calculator Function.The mean NDVI values rangingfrom ((−0.374926 to + .363135)and classified into 5 categories, very high, high, medium, low,very low (**Figure 4.2**.)



Figue 4.1. Rainfall Distribution in Jazan Region in ml/year

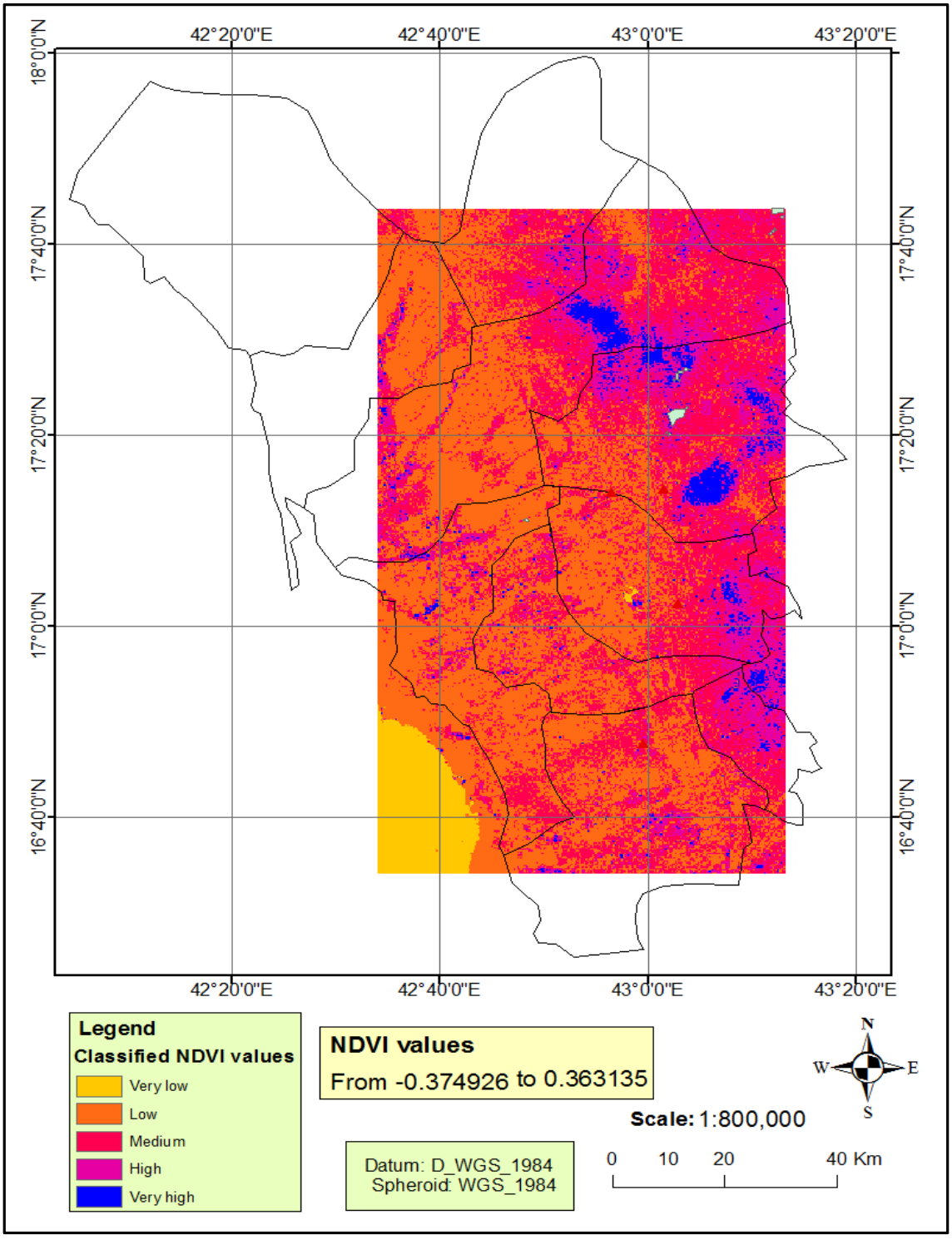


Figure 4.2. Classified average NDVI values of the study area

Figure (4.3) represents the reclassified topoghraphic DEM in Jazan region where low-land enviroments constitute high-risk areas, since water is likely to accumulate there resulting in temporary ground pools that supporting the emergenceofvery large numbers of adult mosquitoes

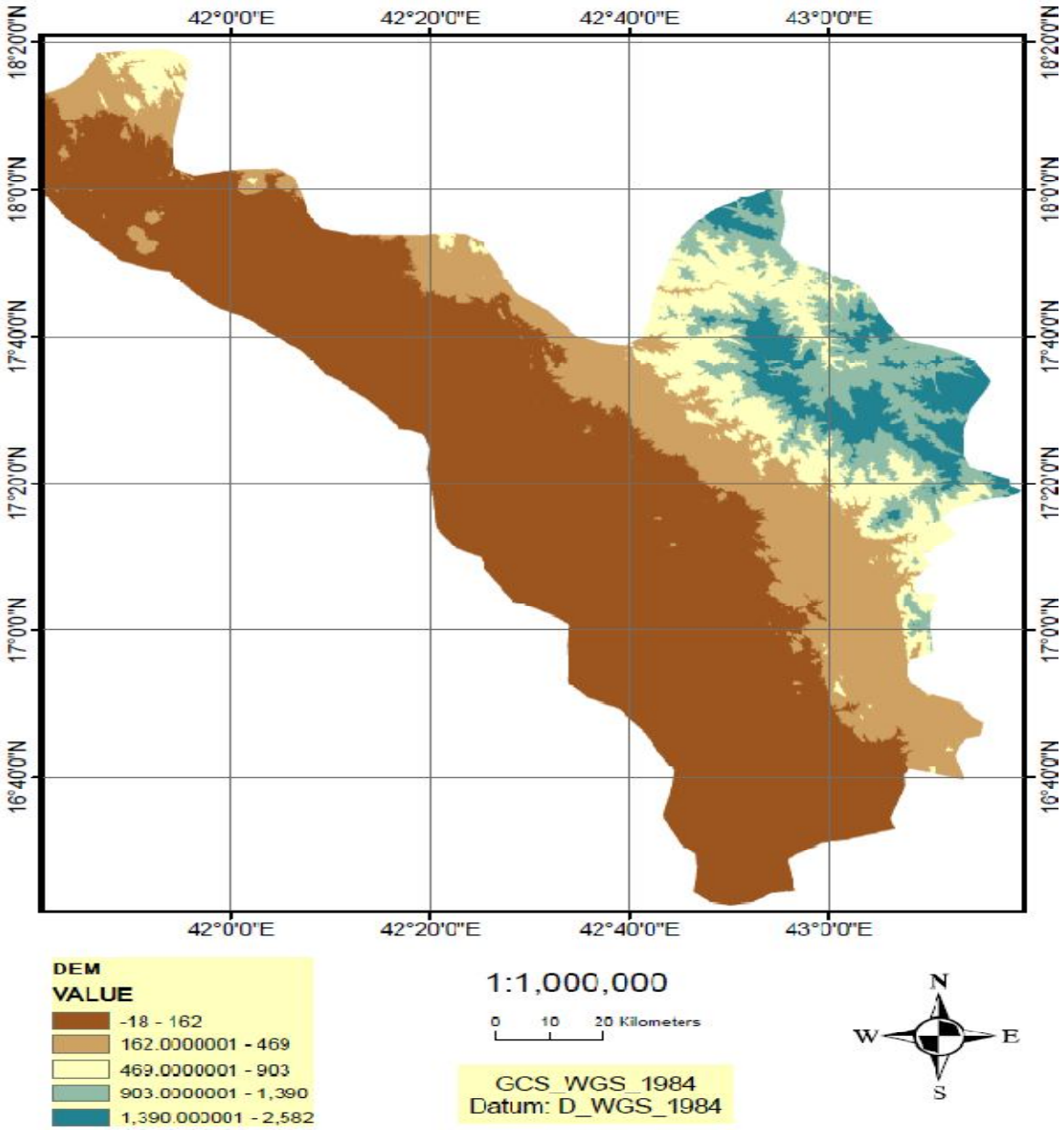


Figure 4.3 : DEM in Jazan Region

4.2.2.vector Variables

Mosquito surveillance data revealed thatexceptionallyhigh densities of adult mosquitoes ranged from 2168 to 16023 mosquitowere recorded in Al-ardah, Gizan and Baish. **Figure (4.4)**.

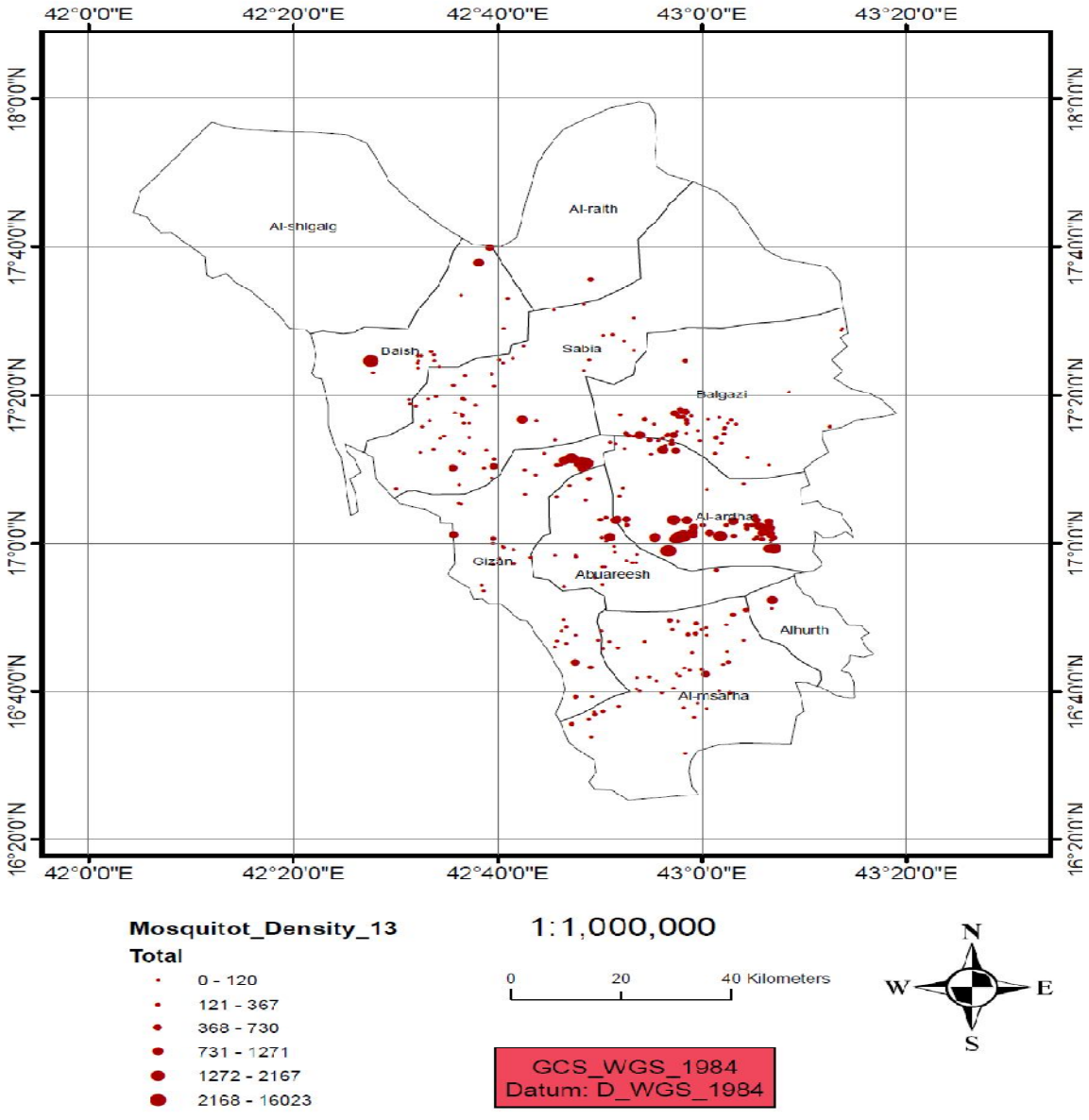


Figure 4.4 : Mosquito density in Jazan Region

As shown in (**Figure 4.5),** the inverse distance weighted toolwas used to estimate mosquito density at unsampled locations. The IDW interpolatorpredicted high mosquito abundance in Alardah, Gizan and Baish

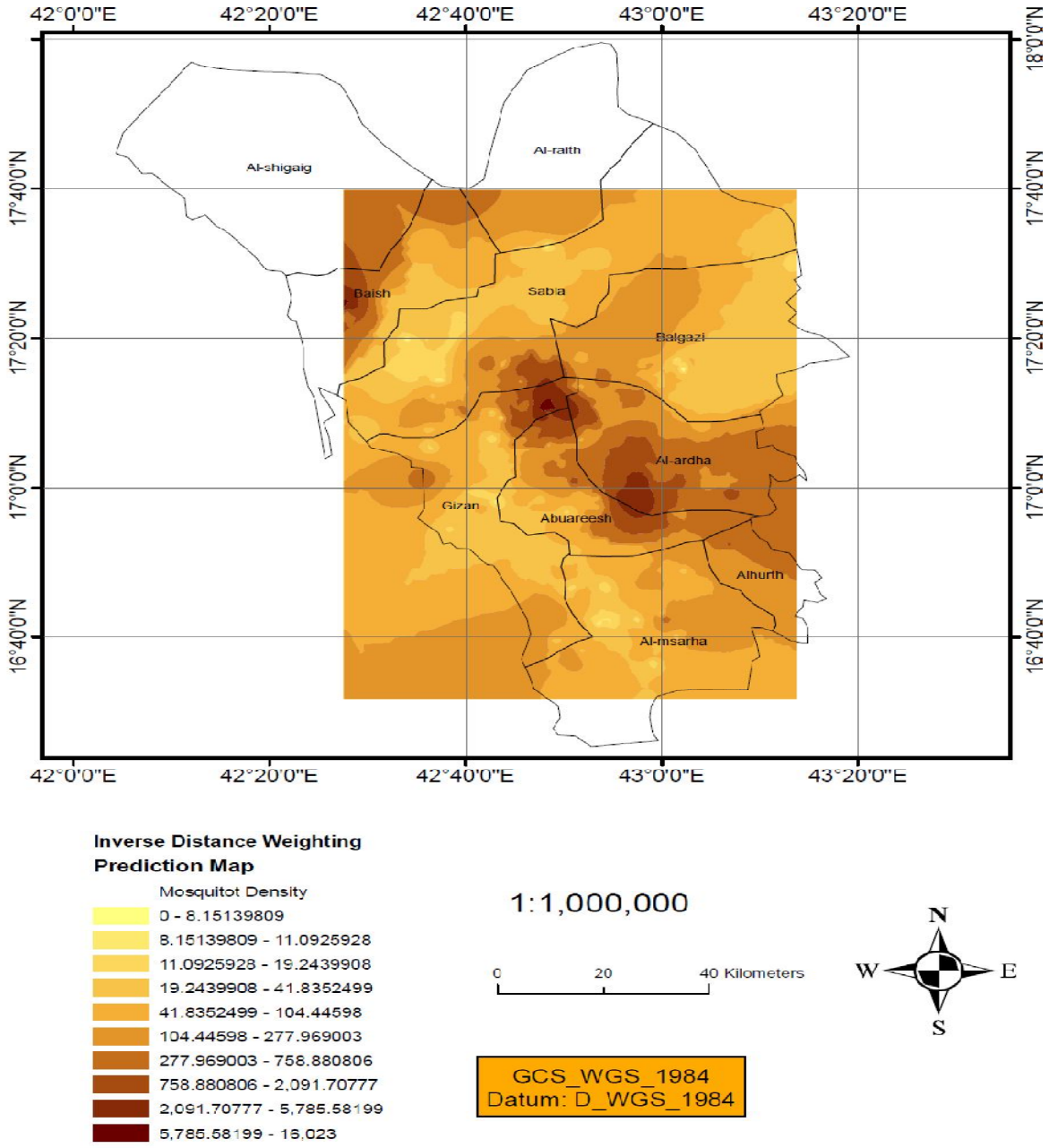


Figure 4.5. Prediction map for Mosquito Density by Ineverse Weighted Distance

Hotspots and coldspots analysis was used to estimate the spatial distribution and significant variations in mosquito abundance throughout the region.The results of the analysis indicated that mosquito hotspots were more likely to be located inAlardah, Gizan and Abuareesh.On the contrary, coldspots were detected in Sabia, Almsarha and Bulgazi**Figure (4.6)**.

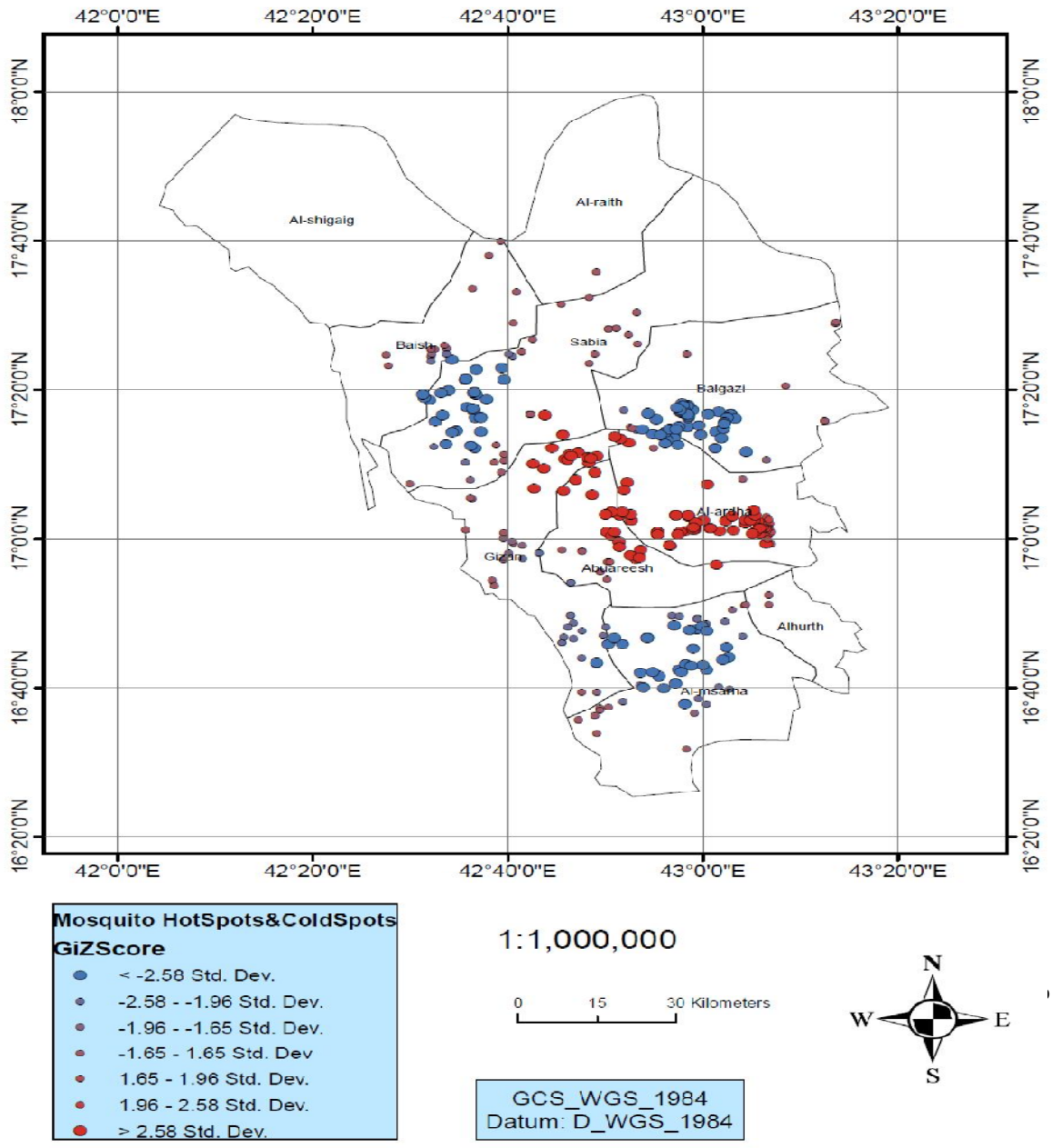


Figure 4.6. Hotspots and coldspots of mosquito in Jazan Region

The geographic distribution and the spatial variabilityof *Aedes* mosquitoes throughout the region, were predicted by using ordinarykriging method. The geostatistical analysis revealed different levels of variability for Aedes distribution in the region. However, *Aedes* species were found abundantly distributed in Alardah, Sabia, Baish and Bulgazi ***(*Figure 4.7**).

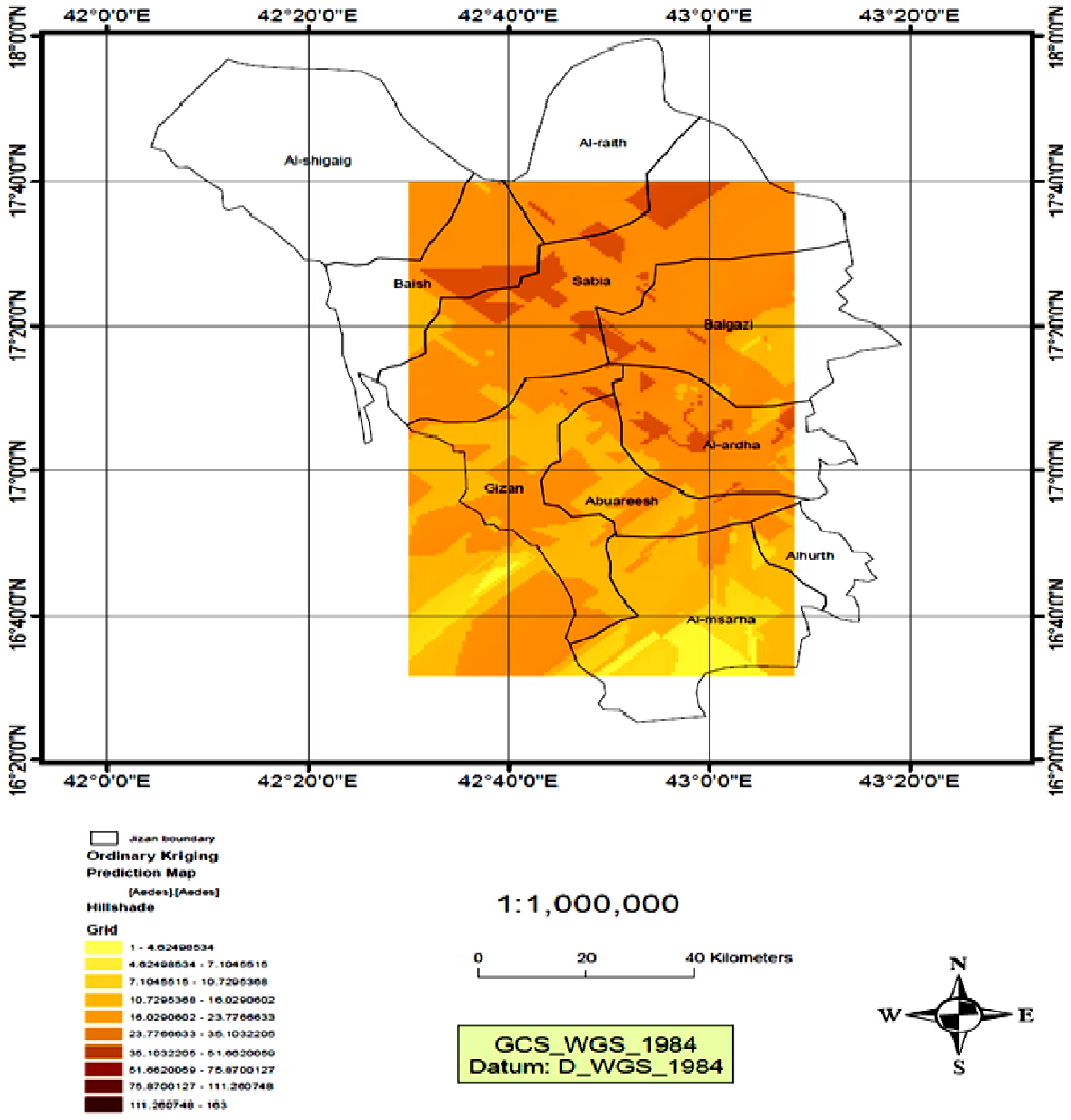


Figure 4.7 : Distribution of Aedes Mosquito in Jazan Region

The distribution of *Aedes*mosquito is shown in **figure (4.8).**It was found that 94.6% of themwere abundantly distributed at low elevations below 469 m.

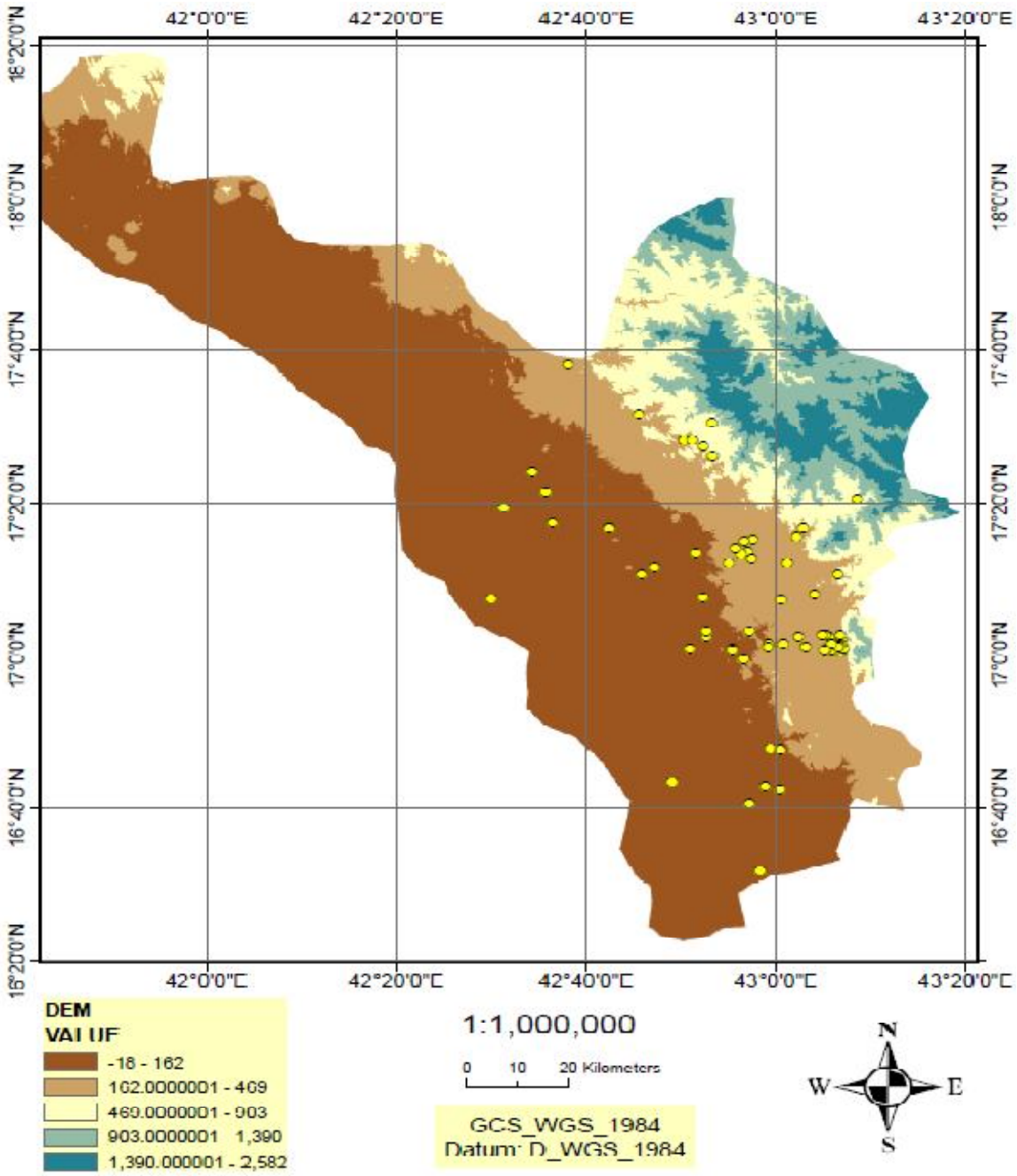


Figure 4.8 : **Distribution of Aedes mosquito in Jazan Region**

The spatial distribution of mosquito breeding sites indicated high incidence of breeding sites in Alardah and Bulgazi (39% and 20%) respectively**figure (4:9)**,(**4.10**).

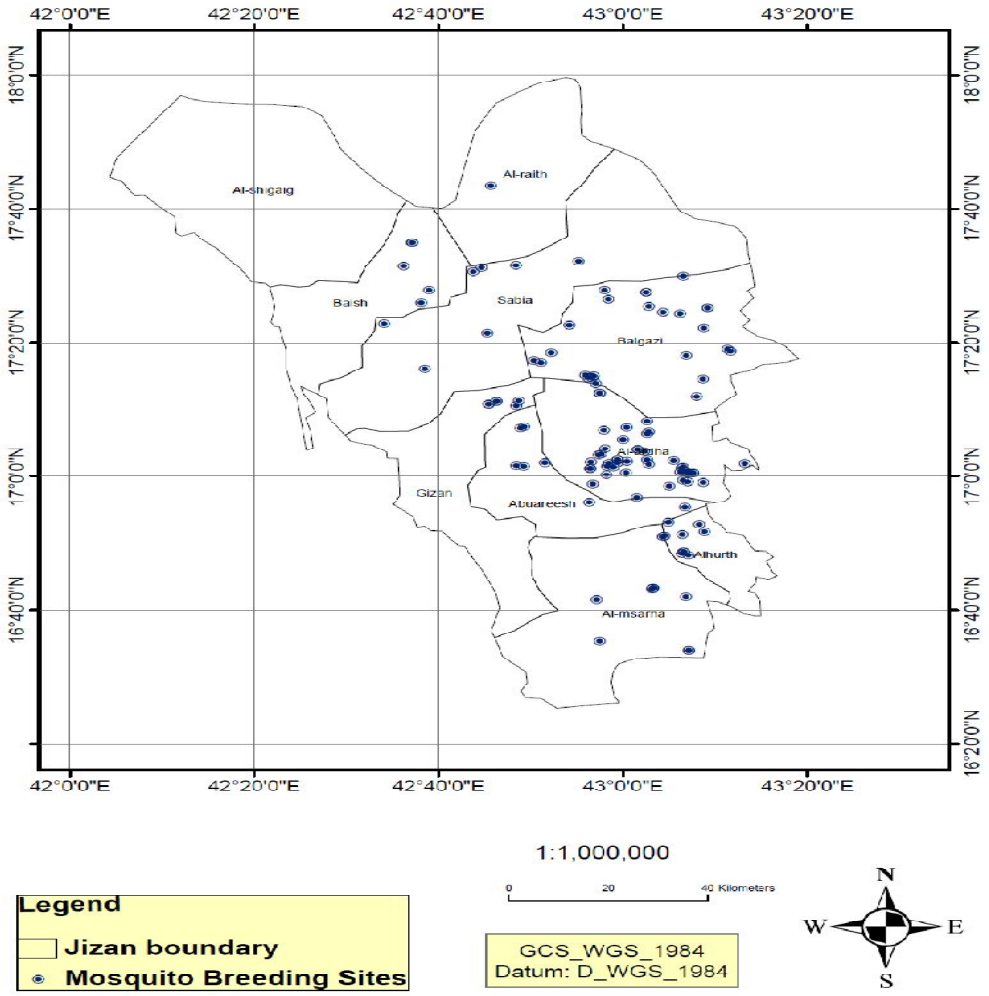


Figure 4.9. Mosquito breeding sites in Jazan region

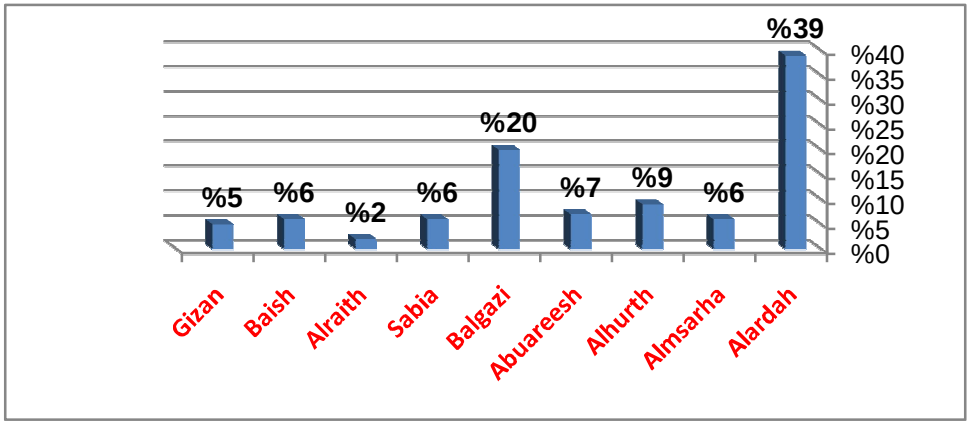


Figure (4.10): Mosquito breeding sites in percent

4.2.3. Animal risk factor variables

Figure(4.11) represents the distribution of animal population in Jazan region. However, high animal population ranged from 502662 -788520 was reported in Sabia, Almsarha and Alardah.

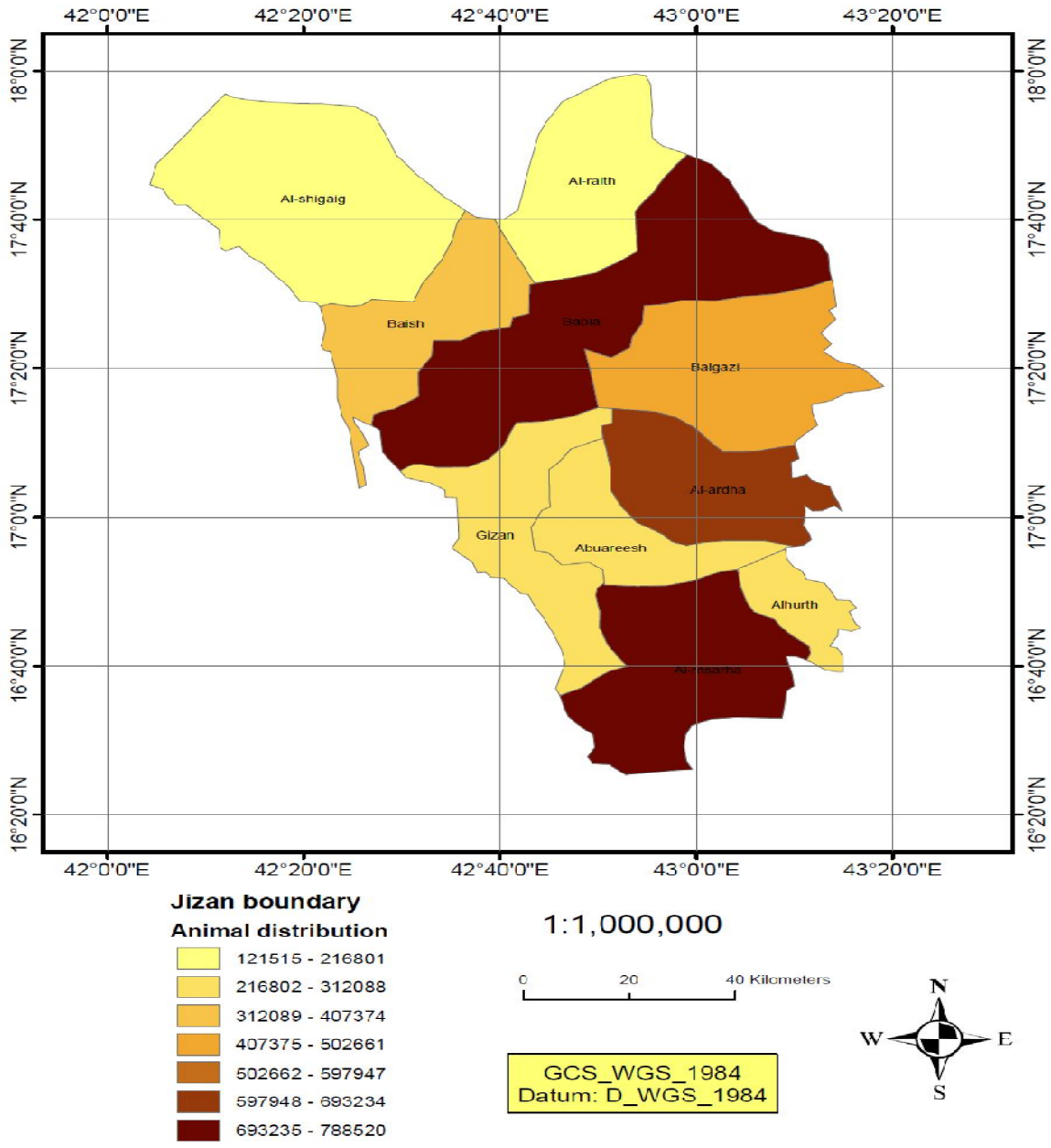


Figure 4.11. Animal Distrubution in Jazan Region

The spatial analysis of RVF cases that occurred in jazan region during the 2000 outbreakindicated that allrelated cases of RVF were reported at altitudes between 14-1380 m**(Figure 4.12**).While, most cases (91.7%) seem to occur in areas as low altitudes as between (14-502m), (**Table 4.4.**).

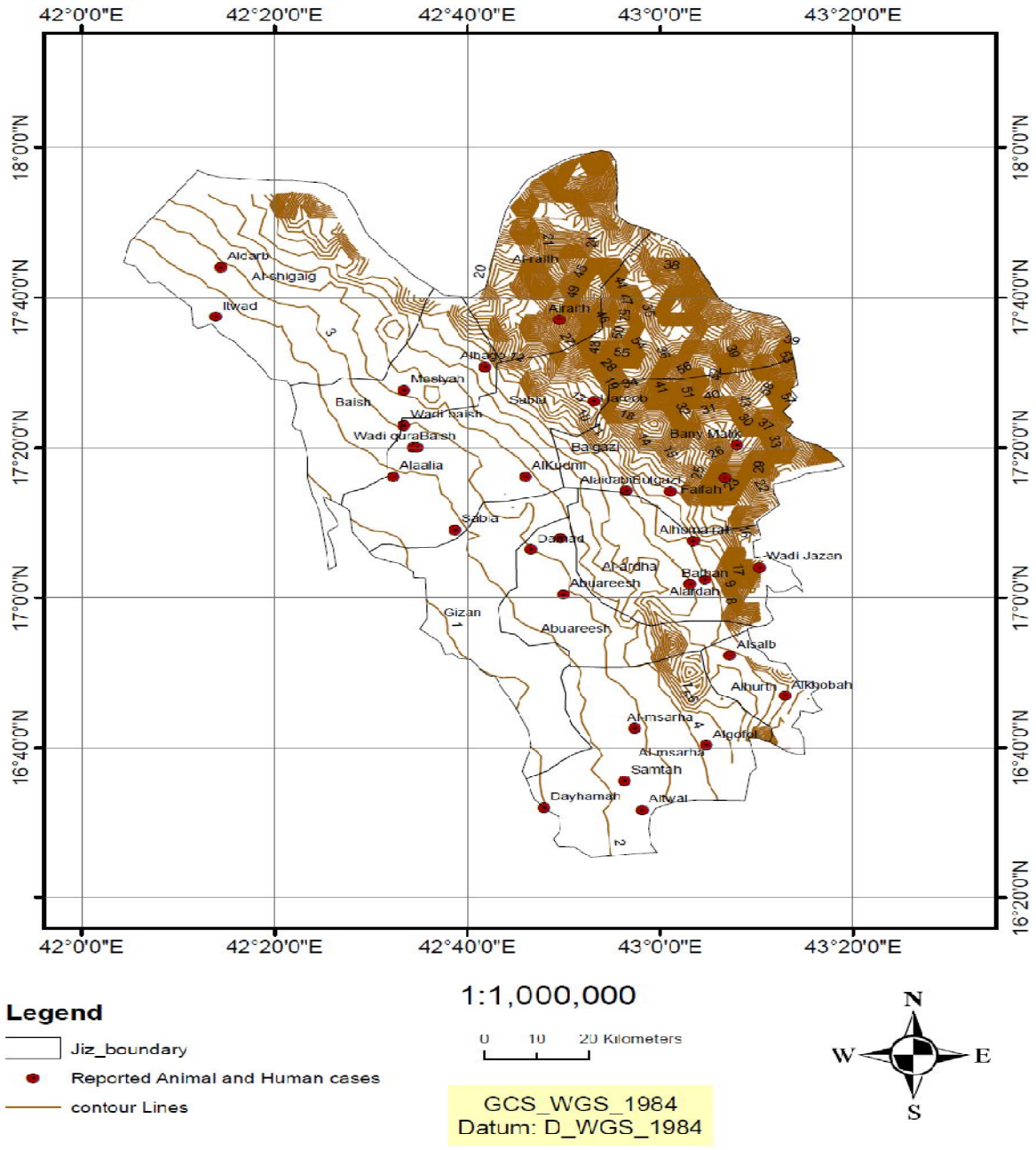


Figure 4.12. Reported animal and human cases of RVF in 2000 outbreak

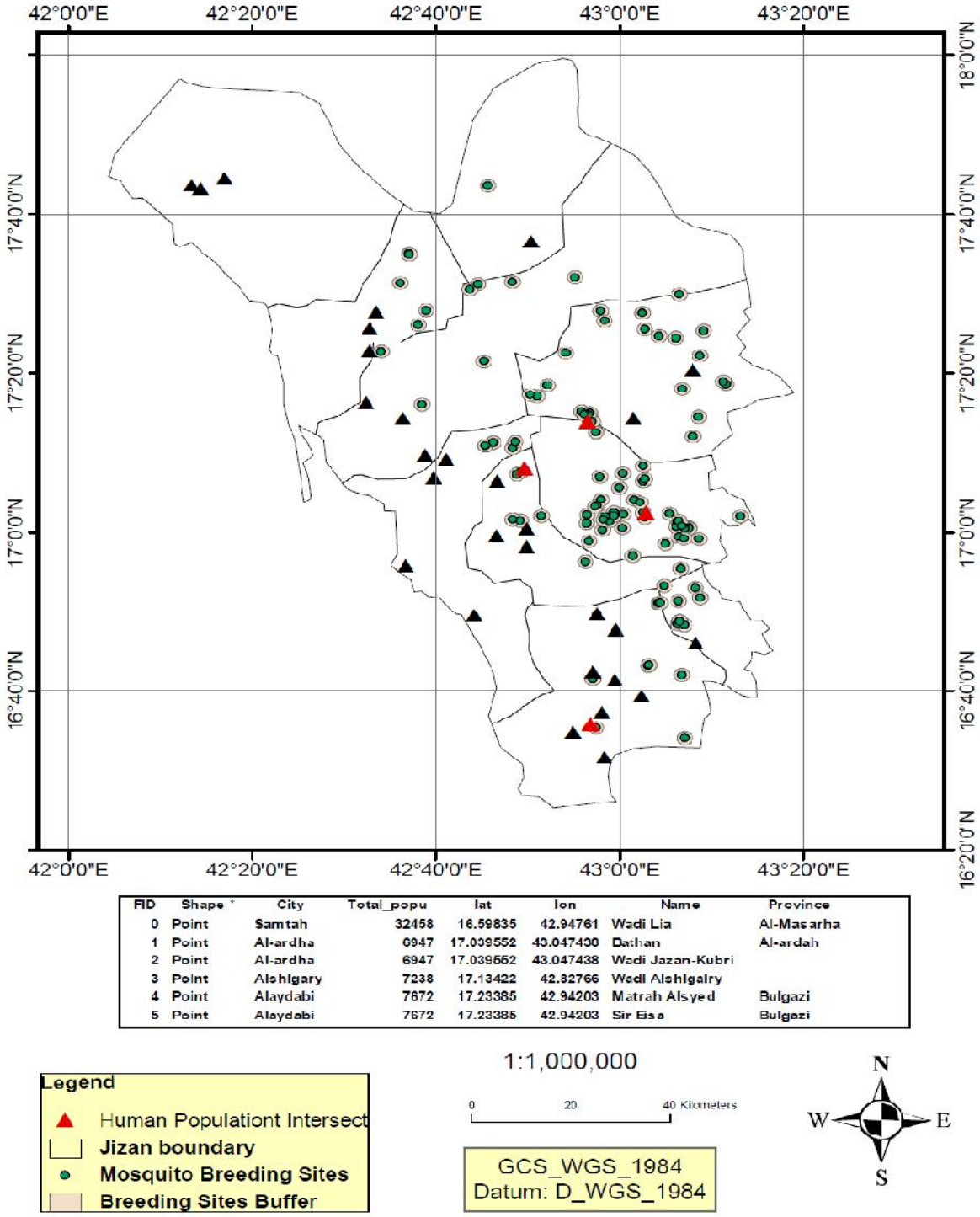
Table 4.4: Distribution of Animal and Human cases by Elevation

SN	Location	Number of Animal cases	Number of Human cases	Contour line
1	Dayhamah	4	2	1
2	Altwal	7	3	2
3	Bathan	10	5	7
4	Almowsam	5	0	1
5	Algofol	2	1	4
6	Samtah	11	5	2
7	Alkhobah	41	12	8
8	Al-msarha	26	5	3
9	Wadi Jazan	2	0	22
10	Alsalb	65	9	8
11	Alardah	47	24	8
12	Abuareesh	12	3	3
13	Damad	17	0	3
14	Alhomairah	173	1	9
15	Wadi baish	10	1	3
16	Bulgazi	35	12	9
17	Sabia	45	2	2
18	Bany Malik	27	1	25
19	Alshigairy	28	1	3
20	Faifah	48	0	43
21	Alaidabi	48	2	7
22	Alaalia	1	1	2
23	AlKudmi	42	2	3
24	Baish	25	1	2
25	Alhago	2	1	7
26	Itwad	1	0	1
27	Maslyah	37	0	4
28	Haroob	162	19	16
29	Wadi qura	5	0	2
30	Aldarb	13	0	3
31	Alraith	39	6	32
32	Alhudon	1	0	2
33	Alrakobah	2	0	2
34	Aledabi	1	0	7
35	Alkhobah	3	0	9
36	Alkhadrah	2	0	2

37	AlKudmi	3	0	Contour line
38	Alrakobah	3	0	2
39	Almoger	1	0	4
40	Albager	3	0	8
41	Albahteet	2	0	8
42	Khabt Albager	1	0	8
43	Almoger	1	0	4
44	Almoger	2	0	4
45	Amaldood	1	0	7
46	Wadi shahdan Alkudmi	5	0	4
47	Khabt Albager	1	0	9
48	Alshigairy	1	0	3

4.2.4. Human Risk Factors Variable

In this study the GIS analysis tool intersest wasused to perform the intersection between mosquito breeding sites and human population in cities that have a population more than 4000 persons to identify human populations who are at risk of mosquito bites. The resultsindicated that around 54315 persons in cities of Samtah, Alardah, Alshigairy and Alaydabi (32458, 6947, 7238, and 7672 persons respectively, are located nearby mosquito breeding sites and much more likely to have mosquito-borne diseases (**Figure 4.13**).



FID	Shape *	City	Total_popu	lat	lon	Name	Province
0	Point	Samtah	32458	16.59835	42.94761	Wadi Lia	Al-Masarha
1	Point	Al-ardha	6947	17.039552	43.047438	Bathan	Al-ardah
2	Point	Al-ardha	6947	17.039552	43.047438	Wadi Jazan-Kubri	
3	Point	Alshigary	7238	17.13422	42.82766	Wadi Alshigalry	
4	Point	Alaydabi	7672	17.23385	42.94203	Matrah Alsyed	Bulgazi
5	Point	Alaydabi	7672	17.23385	42.94203	Sir Eisa	Bulgazi

Figure 4.13.Intersection between mosquito breeding sites and human population

The proximity analysis that was conducted to predict human populations who were at risk of mosquito borne diseases based on 1.5 Km buffer zone around mosquito traps suggested that about (24,486) people in Alardah, Aljadiah, Alaedabi and Bulgazi reside within mosquito flight range and more likely to be affected by mosquito bites(**Figure 4.14**).

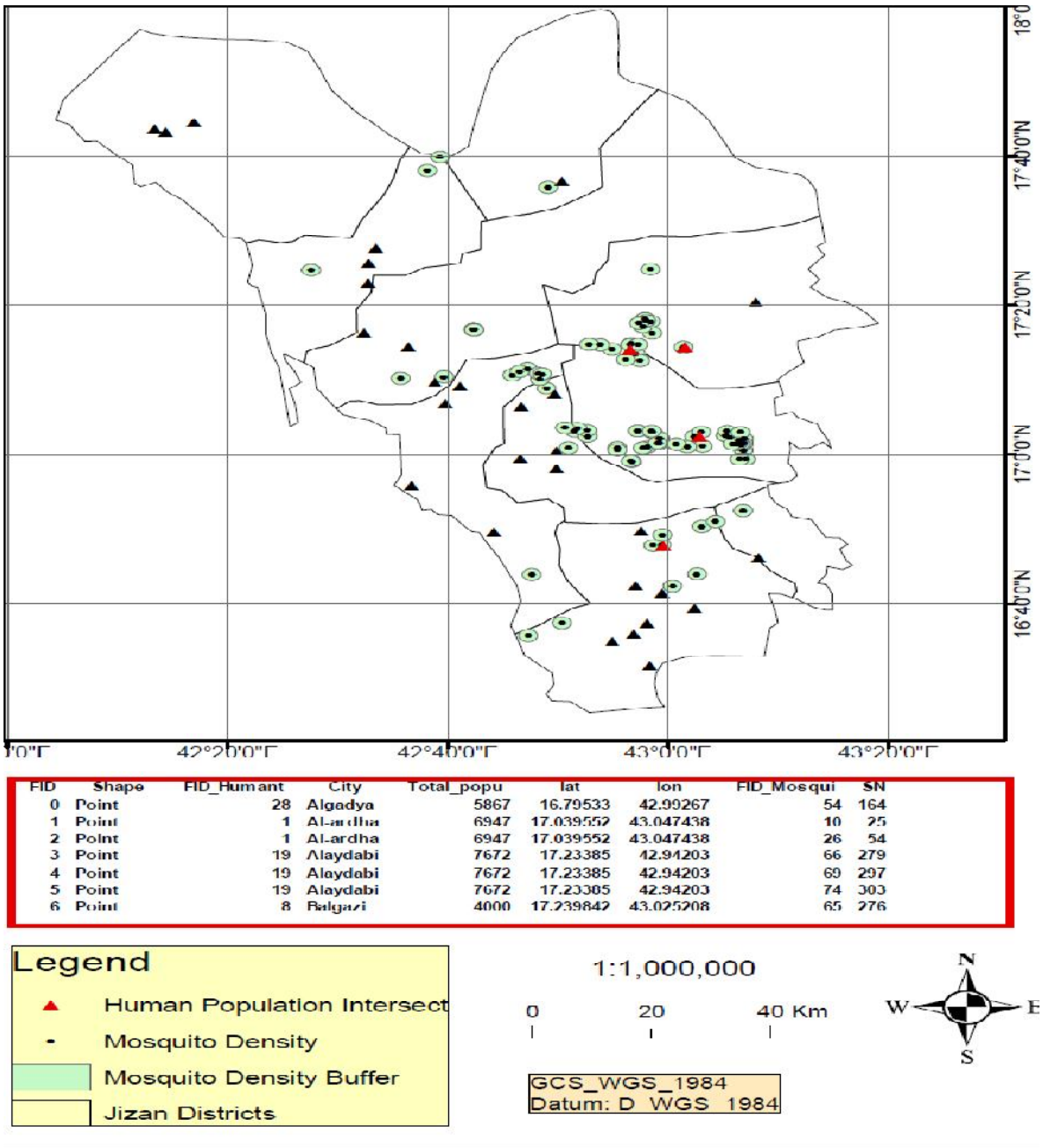


Figure 4.14. Human Population and Mosquito Density intersection

4.2.5. RVF Risk Model

The study revealed thatthe very high risk area,high risk and medium risk area were mostly concentrated around the middle and the Easternpart of the region. The model outcome suggests that, the very high risk zones were located in Sabiadistrict, while both of Sabia and Balgazi districts were predicted as having high probability of RVF occurrence**(Figure4.15**).Most importantly,nearly 5000 persons in Aledabi city were located within high-risk zones.

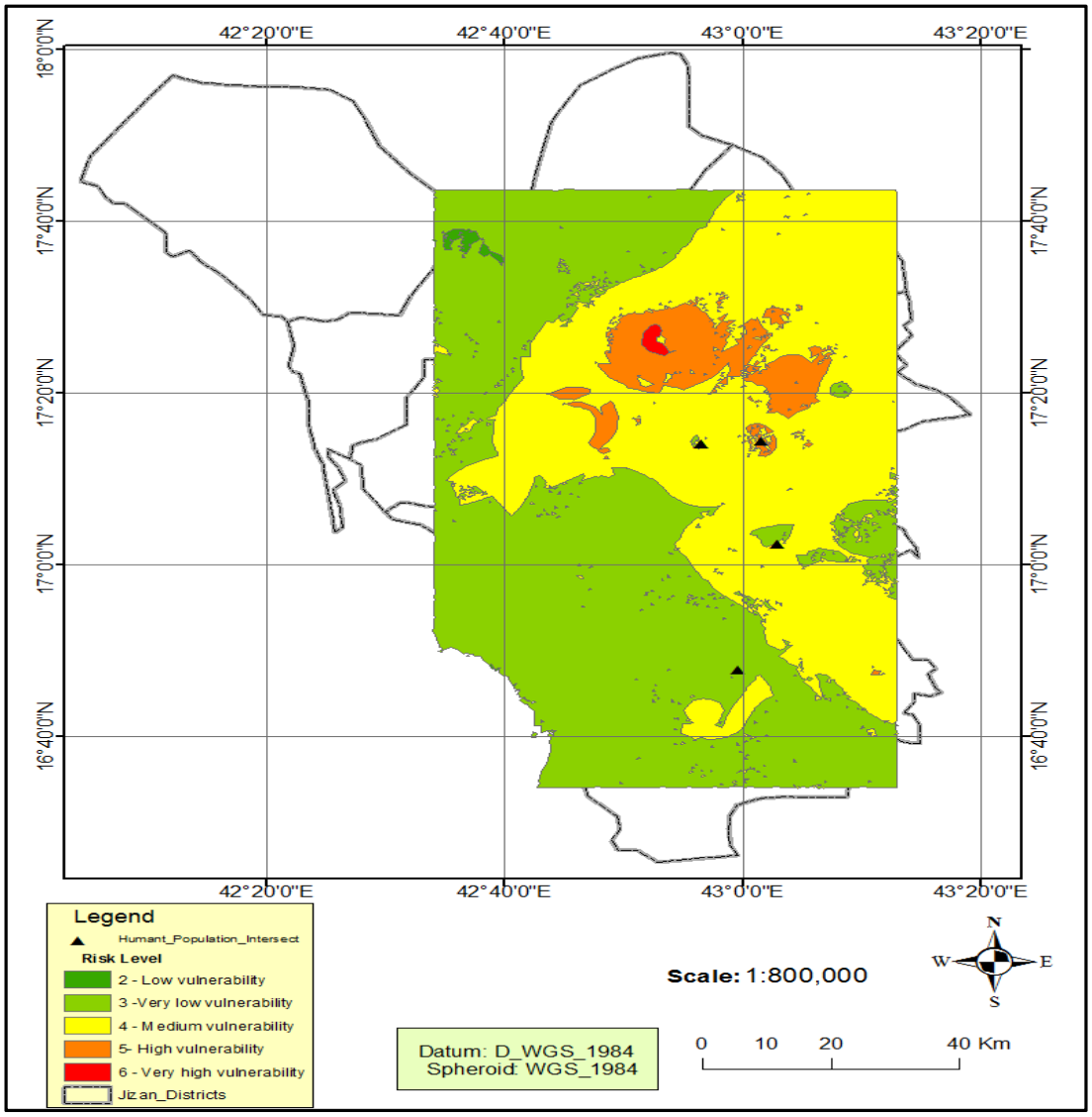


Figure 4.15. Final Risk Map for RVF

Table 4.5 summarizes the potential epizootic areas for RVF and the boundaries of intervention activities.The calculated risk area per Km^2 for the very high vulnerability, high vulnerability and medium were (16.13$\boldsymbol{Km^2}$), (475.47$\boldsymbol{Km^2}$) and 3577.60$\boldsymbol{Km^2}$ repectively.

Table 4.5. Calculated Risk Area per (Km^2)

Grid code	Rank	Area (m^2)	Area (Km^2)
2	Very low vulnerability	22,992,358.2	22.99
3	Low vulnerability	4,242,911,715.1	4242.91
4	Medium vulnerability	3,577,596,995.8	3577.60
5	High vulnerability	475,469,021.9	475.47
6	Very high vulnerability	16,133,019.1	16.13

Chapter Five

Discussion

Principal results of the current study revealed that *Culex* species was consistently the predominant mosquito, ranged from 98.13% to 99.26% in Sabia and Abuareesh respectively.The geo-spatial analysis estimated that there are about 16.13$Km^2$and 475.47Km^2 of land were identified asvery high risk zones and high risk zones respectively.

The current study indicated that *Culex* and *Aedes* were the most collected mosquitoes in the study area. These resultsare similarto previous findings reported by**Jupp *et al*.,(2002)**during the 2000 outbreak where *Cx.tritaeniorhynchus* and *Ae.v.arabiensis* were incriminated as primary vectors for RVF inJazan**.** Furthermore, the *Culex* abundance rate obtained from this study (94.39%) was almost similar in rates to that previously reported in Sudan during the 2007 outbreak (91.2%) **(Seufi and Galal, 2010).**Contrary to the *Culex*, *Aedes*which was found infrequently distributed(22.4**%)**in this study, reported high abundance rate in Sabia (2.46%), followed by Alardah (02.0%)**.** However, such results highlighted the two districts as high-risk areas for RVF transmission particularly during inter-epizootic periods.

Regarding phlebotmomus Sandflies, several studies have shown that they were involved in vectoring many viruses of great medical and veterinary importance including RVF **(Turell and Perkins,1990).** Preliminary surveys of sanflies revealed that they were the most likely vectors for both cutaneous and visceral leshmaniasis**(Morris *et al*.,2001).** **Al-Zahrani, *et al*.,(1997)** reported that the dominant species in Jazan were (*Phlebotomus sergenti Parrot*) in the highlands and (*P. bergeroti Parrot*) in the lowlands. In both habitats there was a marked seasonal variation in abundance, peak levels in the lowlands preceding the highlands**.**However, the present study indicated that Sandflies were distributed sporadically in altitudes between 24-760 meter above sea level. Moreover, It was found more abundant in Bulgazi, Almsarha and Abuareesh withvalues (5.6%, 4.36% and 3.89)

respectively**.** Such findings were previously recorded in Asir region where (5.12%) and (1.8%) of flies were collected from Sarroat mountains and Asir Plateo **(Ibrahim and Abdoon,2005).**However,the introduction of these flies in the region clearly explained the endimicity ofcutaneous and visceral leishmaniasis in many areas in Jazan region **(Al-Jaser,2006).**

Culicoides are known as the major vectors of economically important arboviruses and particularly arboviruses of domestic livestock such as Blue Tongue, African horse Sickness, Bovine ephemeral fever **(Mellor *et al*.,2000).** Studies that have been conducted in Jazan region to investigate the incidence of Blue Tongue disease reported high prevalence in sheep, goats, cattle and camels (65.8%),(68.2%), (49.3%) and (44%) respectively **(Yousef *et al*.,2012).** Therefore, the observed high incidence rate of BT in Jazan could be justified by the distribution of *Culicodies* in most districts particularly in Almsarha(3.13%) and Abuareesh(2.18%). RT-PCR assay is considered as sensitive and specific test for RVF diagnosis by detecting the genome of the virus. The result of this study showed that all mosquito samples were found negative for PCR test. Historically, molecular investigations demonstrated that, RVFV was circulated in mosquitoes at very low rates even during outbreaks. Likewise, in the 2000 outbreak in Jazan region, only 6 of 15, 428 *Culex tritaenio-rhynchus Giles* and 7 of 8,091 *Aedes vexans arabiensis* were found positive for the presence of RVFV **(Jupp *et al*.,2002).**

The rainfall distribution patterns and amounts indicated that the mean annual precipitation is theheaviest over Bulgazi, Al-ardah,Baish and Al-hurth as high as 370.2 mm, 270.2mm 234.5mm and 203.6 mm respectively. These findings highlighted the above mentioned districts as high-risk of RVF,since most outbreaks in African savannawere more likely tooccur in areas received between 200-800 mm per year of rainfall (**Anyamba *et al*.,2002**). In addition to that, most of these districts including Alardha, Alhurth, and Bulgazi are close to theYemani borders where the disease is endemic in the area of Wadi Mawr in El Zuhrah district, which is located on a coastal plain that extends from the

southern tip of Yemen into the Jizan area of the Kingdom of Saudi Arabia and no control program was adopted in Yemen which could be a potential source of infection**(CDC,2000).**

In this research, the spatial distribution of mosquito breeding sites indicated high incidence of breeding sites in Alardah and Bulgazi (39% and 20%) respectively. These findings are consistant with mosquito density that presented in **Figure (4.4*)*** where very high abundance of adult mosquitoes between (2168-16023 mosquito)were reported in Al-ardah. Concerning the distribution of *Aedes* mosquitoes, the study reported that 94.6% of*Aedes* mosquitoes were abundantly distributed at low elevations below 469 m. These findings are strongly supported by **Davies *et al*.,(1985)** who stated that the heavy rainfall floods the low-land fields constituting aquatic environments that supporting the emergenceof very large numbers of Aedes mosquitoes. The spatial analysis of RVF human and animal cases that occurred in jazan region during the 2000 outbreak indicated that most cases (91.7%) seem to occur in areas as low altitudes as between (14-502m). These results clearly confirmed the provious observations reported by **Nanyingi *et al*.,(2015**) who reported that high incidence of RVF has been reported in areas having soil with poor drainage and flat landforms with low altitudes below 500 m.

The model outcome suggests that, the very high risk zones wereestimated to be (16.13***Km*** ^{2}). These results are in contrast with **Sallamet al., (2013)**, who reportedthat the very high risk area in Jazan regionwas 670.43 km2. In their study, they predicted the risk area based only on the distribution of *Cx. tritaeniorhynchus*. On the contrary, this model was developed based on evirommental, vector, animal and human risk factors, which may be one of the strengths of this research.

The study highlighted the cities of Alardah, Aljadiah, Alaedabi and Bulgazi as hot spots of mosquito borne diseasesas well as Sabia district as very high risk zone for RVF Consequently, Special attention should be given to these areas regarding vector control program, public awareness and self- protective measures.

One potential limitation of this study is that,the temporal abundance of mosquitoes and seasonal variations in abundance are beyond the scope of this study. Another limitation for this study could bethe absence of mosquitoe classification to species level. In light of the shortcomings of this study, conducting more spatio-temporalstudy should be considered in future studies towards implementing more effective control measures against mosquito-borne diseases .

Conclusion

In the current study, the mosquito and *Sandfly* fauna of Jazan region was investigated to identify the density and the geographic distribution of potential vectors of RVFV. Among the collected mosquitoes,*Culex* species was consistently the predominant mosquito, ranged from 98.13% to 99.26% in Sabia and Abuareesh respectively. While, *phlebotomus sandflies*, were found sporadically distributed with high relative abundance in Bulgazi (5.6%).The study further investigated the circulation of RVFV in mosquitoes by RT-PCR.The test revealed that allmosquito samples tested were reported as negative which indicated no viral activity at least for the time being**.**Interestingly**,** at least 54315 persons inthe cities of Samtah, Alardah, Alshigairy and Alaydabi (32458, 6947, 7238, and 7672 persons respectively, are located nearby mosquito breeding sites and much more likely to have mosquito-borne diseases**.**Most importantly**,** the model outcome suggests that, the very high risk zones were located in Sabia district, while both of Sabia and Balgazi districts were predicted as having high vulnerability to RVF occurrence**.**The calculated risk area per Km^2 for the very high vulnerability, high vulnerability and medium were (16.13$\boldsymbol{Km^2}$), (475.47$\boldsymbol{Km^2}$) and 3577.60 $\boldsymbol{Km^2}$ repectively.

Recommendations

1) The present study precisely defined the potential epizootic areas for RVF and calculated the risk area per Km^2 for the very high risk, high and medium risk area. These resultsshould guide prevention and control program effectively. Decision makers should directcontrol programs towardsthe critical areasmainly the very high risk area and high risk zones with more confidence and effectiveness. Furthermore, sentinel herds should be relocated in high and very high risk areas as well as vaccination campaigns should be executed.

2) The geospatial analysis estimated that around 54315 persons in cities of Samtah, Alardah, Alshigairy and Alaydabi fall within mosquito flight range and exposed to mosquito bites. These findings emphasize the need for increasing public awareness among vulnerable populations along with improving people adherence to self-protective measures to prevent vector-borne diseases in humans. However,the possible preventive measures can be summarized as follows: 1) wearing protective equipment over as much of the body as possible to avoid direct contact with suspected animals, body fluids or aerosols. 2) use of mosquito repellent. 3) sleeping under Insecticide-treated bed nets (ITNs). 4) indoor spraying of houses with residual insecticides.

3) Vector control is the backbone of preventing mosquito-borne diseases in highly exposed populations, since, effective vaccines or treatment were not always available for the prevention of vector-borne diseases. There are major problems facing effective vector control programs and remain as ongoing challenge in public health. The two most prominent among these are increasing resistance to commonly used pesticides and the global growing concerns over the use of insecticides in the environment. Consequently, proposed vector control strategies should focus on biological agents and mechanical methods such as modification of larval habitats, rather than traditional pesticides.

4) It is obvious that monitoring the temporal abundance of mosquio is beyond the scope of this study. For this reason, the researcher recommends monitoring the spatio-temporal distribution of vectors, seasonal variations in abundance and monitoring the success of vector control activities. Future vector surveillance efforts should focus on identification of mosquitoes to species level, to establish mosquito database that could be used as a platform for controlling emerging mosquito-borne diseases.

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