Spatial Aspects of Rift Valley Fever Epidemiology in Jazan Region, Saudi Arabia

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Abstract

Rift Valley fever (RVF) is a serious life-threatening disease with severe clinical manifestations and health consequences for humans and a wide range of domesticated animals. In September 2000, a RVF outbreak was reported in Jazan region south-west Saudi Arabia with 886 human cases including 124 deaths. Since the early recognition of RVF in Saudi Arabia, a comprehensive control program has been launched to contain the outbreak, albeit, the existing preventive measures are inadequate. They are obviously lacking the geographical perspective besides the absence of spatial aspects. From these perspectives, the aim of this study was to develop a new risk model based on the spatial relationship between the disease and associated risk factors to identify high-risk zones for RVF in Jazan region, in addition to the locations where people are potentially exposed to RVF as well as to calculate the total population who are potentially exposed to RVF. However, various innovative approaches and novel biotechnological tools including, but not limited to GIS (Geographical Information System) technology, GPS (Global Positioning System), satellite images, and field observation techniques were used in the current study. These data i.e. the NDVI, average rainfall, water bodies, mosquito breeding sites, animal and human distribution, reported animal and human cases, aedes distribution, and positive sero surveillance were input in the Weighted Overlay Tool (included in the Spatial Analyst Tools of ArcGIS 10.2) as the main tool of the model which yielded the following results.

The results of this research indicated 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. There are about 16.13 Km² of land under very high risk, 475.47 Km² under high risk, and 3577.60 Km² under medium risk. Interestingly, at least 54,315 persons in the cities of Samtah, Alardah, Alshigairy and Alaydabi are located nearby mosquito breeding sites and much more likely to have mosquito-borne diseases.

The outcome of this study could enhance the existing RVF surveillance and preventive measures effectively over the long time as well as enable decision makers to focus limited resources on areas at high risk of the disease.

Key words: RVF - GIS - GPS – Risk Map – RVF.

Introduction

RVF is a serious infectious disease in humans and a wide range of domestic ruminants, caused by mosquito-borne virus that belongs to the family Bunyaviridae, genus phlebovirus. Human can be infected either by mosquito bites or through the exposure to

blood, aborted fetal materials, body fluids, or tissues of RVF-infected animals^[1]. It was first reported among livestock in Kenya in 1931, since then it has been reported as occurring not only in most African countries, but also in Arabian Peninsula, particularly in Saudi Arabia and Yemen^{[2],[3]}. The first occurrence of the RVF in new geographical areas outside Africa was reported in Jazan region, south-west Saudi Arabia in the year 2000^[4]. 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^[5]. 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^[6]. Species of mosquito that previously are incriminated as potential vectors for RVF vary between regions^[7]. Several mosquito species serve as principal vectors and able to transmit the virus by bites, most notably those belonging to the genus *Aedes* which is thought to play a significant role in maintaining the endemicity of the disease in the environment through transovarial transmission^[8]. Recently, geographical information system (GIS) has gained much more interest worldwide in public health, epidemiology and surveillance programs. Most professionals are becoming highly involved in GIS and increasingly dependent on integrated use of spatial information and dynamic analysis^[9], the application of GIS technology in control of infectious diseases that threaten the livelihoods of millions of people is promising. GIS can be applied to illustrate the distribution of infectious diseases, examine risk factors and detect populations at risk of infection, especially when integrated with Global Positioning System (GPS) and remote sensing technologies^[10]. Moreover, GIS has 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^[11]. 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 Rift Valley 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^[12]. 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^[13]. Since the early recognition of RVF in 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, entomological surveillance, virus detection in mosquitoes by molecular techniques, serological surveillance and sustaining vaccination campaigns. Although these measures contribute significantly to RVF control over the past sixteen-years, there are still some gaps and significant limitations. The potential epizootic area for RVF as well as human and animal populations at risk of contracting RVF are not accurately defined. Moreover, the geographical distribution of mosquitoes according to coordinates has not yet been adequately addressed. Furthermore, very little is yet known about the boundaries of intervention area, the spatial pattern and the extent of the disease. From these perspectives, the aim of this study was to: 1) identify potential epizootic areas for RVF and the boundaries of intervention activities, 2) build a risk model for RVF to identify high risk areas that may prone to outbreaks, based on RVF associated risk factors and according to the mapping capabilities of GIS and its ability to combine multiple individual layers of data into a single map. The study strives to provide new insight into disease control and contribute to establishing a forecasting system for RVF along with strengthening surveillance and response system effectively over the long time.

Materials and Methods

Study Area and Population

Jazan region is located on the farthest south-west Saudi Arabia between longitudes 41.0213°E and 43.3377° E and latitudes 16.0943°N and 18.3281°N, 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 KM² and it is divided into 13 governorates and 31 districts. The terrain of the region varies and consists of mountains, coastal and fertile plains^[14]. 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^[15]. 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^[16]. 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 activities which eventually provide an ideal habitat for RVF vectors.

Software Package

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

Data Sources and collection methods

The GIS data sets used 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 and DEM(*table 1*). These data were collected by field observations, from satellite images and veterinary records that belong to the General Administration for Agricultural Affairs in Jazan-Ministry of Environment, Water and Agriculture-KSA.

Database Components

The current GIS database is grouped into four sets of variables serving as potential indicators for RVF occurrence. These variables include: 1) environmental risk factors variables, 2) vector variables, 3) animal risk factor variables, and 4) human distribution variables (*Table 1*).

Table (1). Database Components

Variable	Description
1 Environmental and climatic Variables	
Rainfall Data	Average monthly rainfall expressed in millimeters for the period 2005-2015,(Excel sheet containing GPS acquired points, from which an ESRI point shapefile was created then a surface showing the rainfall distribution was created using the Inverse Distance Weighted interpolation tool)
NDVI	NDVI average values for the period 1987-20150, were produced from Landsat images (InfraRed and Red bands)

		of the study area using ArcGIS10.2 to show the vegetation distribution.
	DEM	Digital Elevation Model was used to map the water accumulation sites (catchments), and to produce the slope of the study area.
2	Vector Variables	
	Breeding habitats	Water bodies within the study area (Water pools, , valleys, sewage stations, and dams)
	Vector Density	The average number of mosquitoes in trap per site. GPS points in Excel sheet were processed same as rainfall data.
	Vector Distribution Data	Location of mosquito by species, based on geographic latitude and longitude. GPS points in Excel sheet processed same as rainfall data.
3	Animal and human Risk Factors Variables	
	Livestock Distribution	Visualization of high density areas (Excel sheet containing GPS acquired points, from which an ESRI point shapefile was created then a surface showing the Euclidean distances from the locations of the livestock was created using the Inverse Distance Weighted interpolation tool)
	Reported cases in 2000 outbreak	Animal and Human reported cases in 2000 (Excel sheet containing GPS acquired points, from which an ESRI point shapefile was created then a surface showing the Euclidean distances from the locations of the reported cases in 2000 outbreak was created using the Inverse Distance Weighted interpolation tool)
	Positive sero-surveillance cases	Recent and previous confirmed positive cases during sero-surveillance (processed same as the above Excel sheet data)
	Positive cases in Sentinel Herds	Reported cases in Sentinel Herd from 2004-2017 (processed same as the above Excel sheet data)
4	Distribution of Human Population	Visualization of cities with more than 4000 people (processed same as the above Excel sheet data)

Environmental and Climatic Variables

Environmental and Climatic Variables were used to identify high risk zones as they are often related to disease incidence and profoundly influence the survival of vectors and virus infectivity as well ^[17]. These variables are controlled by several factors including rainfall, normalized difference vegetation index and topography of the area (DEM). The elevation data were used to predict water accumulation in low lying areas that are associated with aquatic habitats. The long term mean values of NDVI from 1987 to 2010 were calculated from Landsat image for the same period. The monthly mean rainfall was extracted from a long term dataset of rainfall during the period between July 2000 and October 2015, these data were obtained from (http://app.mowe.gov.sa/DailyRainsNews/Rain_Dams.aspx)

Vector Variables

Several factors contribute to the emergence of arboviruses, including proximity to breeding habitats, vector density, proportion of infectious mosquitoes and biting rates^[18]. In the current study, the authors measured vector density as the mean number of mosquito in each trap site, while vector distribution was perfectly represented by longitude and latitude coordinates for each mosquito species. This work was done through mosquito surveillance.

Animal Risk Factor Variables

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

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, the authors mapped the distribution of human in cities with population numbers exceeding 4,000 people.

Geospatial Analysis

Different GIS operations and geo-processing tools, including the weighted overlay tool, buffer tool, statistical analysis, Euclidean distance calculation and digital elevation model processing (to get the slope of the study area), were considered in the analysis for a better understanding of the disease incidence^[19]. In this study, the researcher combined multiple reclassified individual layers of NDVI, DEM, slope, average rainfall, animal and human distribution and mosquito breeding sites buffer zone, into a single map to create one layer which represents the high risk areas that are most likely prone to RVF outbreaks.

Spatial 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^[20]. In this study, the authors developed a new risk model to identify high-risk area for RVF in Jazan region based on the spatial relationships between the disease and associated risk factor variables. The data involved in building the model were used as criteria (i.e. layers) to be input to the model processes and to string the processes together to lead finally to a suitable result. The criteria (layers) were grouped as follows:

- A) Environmental criteria i.e. 1) average NDVI, 2) rainfall, and 3) digital elevation model layers.
- B) Vector criteria i.e. 4) mosquito breeding sites, 5) Aedes density, and 6) mosquito density.
- C) Human criteria i.e. 7) human population distribution, and 8) RVF positive cases among the residents of the study area.
- D) 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.

Hence, the researchers used the tool: *Spatial Analyst Tool – Reclass – Reclassify* to reclassify each of the 11 criteria (layers). The weighted overlay tool (WOT) overlays several raster layers using a common measurement scale (from 1 to 10 by 1) and assigns influence to each of the layers according to its importance. The WOT was used in the first step to overlay

the individual layers (criteria) of each group separately **Fig (1)**, which shows as an example the two layers (Surface showing animals' population concentration after being reclassified into the common measurement scale of 1 to 10 by 1, and the Surface showing the human population concentration after also being reclassified into the same common measurement scale of 1 to 10 by 1). These two processes were executed for all the other suitable factors. In the next step, the groups of factors variables were input in the weighted overlay tool, assigning suitable influence to each group (provided that the total of influence = 100%) and the WOT was run to get the output of overlay which is named Weighted Overlay 5, as shown in **Fig (2)**.

Fig (1): Sample of the process for weighted overlay

Fig (2): the process of the weighted overlay of the 4 groups

Results

The current study investigated some spatial aspects that influence the epidemiology of RVF to strengthen disease surveillance and response system effectively. The study further investigated locations where humans are potentially exposed to RVF and identified the hot spot and cold spot points of vector density. Furthermore, the researchers 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, the authors constructed

statistical spatial risk model to identify high-risk zones that could be targeted with preventive interventions.

Geospatial Analysis

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

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 the heaviest over Bulgazi, Al-ardah, Baish and Al-hurth as high as 370.2 mm, 270.2mm 234.5mm and 203.6 mm respectively **Fig (3)**.

Fig 3. Rainfall Distribution in Jazan Region in ml/year

Additionally, NDVI images were extracted from landsat for 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 ranging from ((- 0.374926 to + .363135) and classified into 5 categories, very high, high, medium, low, and very low (**Fig 4**)

Fig (4) Classified average NDVI values of the study area

Fig5 : DEM in Jazan Region

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Fig (7) Prediction map for Mosquito Density by Inverse Distance Weighted tool

As shown in (**Fig 7**), the inverse distance weighted tool was used to estimate mosquito density at unsampled locations. The IDW interpolator predicted high mosquito abundance in Alardah, Gizan and Baish

Fig 8. Hotspots and coldspots of mosquito in Jazan Region

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 in Alardah, Giza and Abuareesh. On the contrary, coldspots were detected in Sabia, Almsarha and Bulgazi **Fig(8)**.

The geographic distribution and the spatial variability of *Aedes* mosquitoes throughout the region, were predicted by using ordinary kriging 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 (**Fig 9**).

Fig 9: Distribution of Aedes Mosquito in Jazan Region

Fig 10 : Distribution of Aedes mosquito in Jazan Region

The distribution of *Aedes* mosquito is shown in **Fig (10)**. It was found that 94.6% of *Aedes* mosquito were abundantly distributed at low elevations below 469 m. The spatial distribution of mosquito breeding sites indicated high incidence of breeding sites in Alardah and Bulgazi (39% and 20%) respectively **Fig(11)** and **(12)**.

Fig 11. Mosquito breeding sites in Jazan region

Fig (12): Mosquito breeding sites in percent

Animal risk factor variables

Fig (13) represents the distribution of animal population in Jazan region. However, high animal population ranged from 502,662 -788,520 was reported in Sabia, Almsarha and Alardah.

The spatial analysis of RVF cases that occurred in Jazan region during the 2000 outbreak indicated that all related cases of RVF were reported at altitudes between 14-1,380 m (**Fig**

14). While, most cases (91.7%) seem to occur in areas as low altitudes as between (14-502 m).

Fig 13. Animal Distrubution in Jazan Region

Fig 14. Reported animal and human cases of RVF in 2000 outbreak Human Risk Factors Variable

In this study the GIS analysis tool “*intersect*” was used to perform the intersection between mosquito breeding sites and human population in cities that have population more than 4,000 persons to identify human populations who are at risk of mosquito bites. The results indicated that around 54,315 persons in cities of Samtah, Alardah, Alshigairy and Alaydabi (32,458; 6,947; 7238 and 7,672 persons, respectively, are located nearby mosquito breeding sites and much more likely to have mosquito-borne diseases (**Fig15**).

Fig 15. Intersection between mosquito breeding sites and human population

Fig 16. Human Population and Mosquito Density intersection

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 (**Fig16**).

RVF Risk Model

The study revealed that the very high risk area, high risk and medium risk area were mostly concentrated around the middle and the Eastern part of the region. 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 probability of RVF occurrence (**Fig17**). Most importantly, nearly 5,000 persons in Aledabi city were located within high-risk zones.

Fig 17. Final Risk Map for RVF

Table 2 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 (16.13Km^2), (475.47Km^2) and $3,577.60\text{Km}^2$ respectively.

Table 2: 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

Discussion

Principal results of the current study revealed that: The calculated risk area in Km^2 for the very high vulnerability, high vulnerability and medium were (16.13 Km^2), (475.47 Km^2) and 3,577.60 Km^2 respectively. The geo-spatial analysis estimated that there are about 16.13 Km^2 and 475.47 Km^2 of land were identified as very high risk zones and high risk zones, respectively.

The rainfall distribution patterns and amounts indicated that the mean annual precipitation is the heaviest over Bulgazi, Al-ardah, Baish and Al-hurth as high as 370.2 mm, 270.2 mm, 234.5 mm and 203.6 mm, respectively. These findings highlighted the above mentioned districts as high-risk of RVF, since most outbreaks in African savanna were more likely to occur in areas that received between 200-800 mm per year of rainfall^[21]. In addition to that, most of these districts including Alardha, Alhurth, and Bulgazi are close to the Yemani 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^[22].

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 consistent with mosquito density that are presented in **Fig (6)** where very high abundance of adult mosquitoes between (2,168-16,023 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)**^[23], who stated that the heavy rainfall floods the low-land fields constituting aquatic environments that support the emergence of 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 previous observations reported by **Nanyingiet al., (2015)**^[24], 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 were estimated to be (16.13 Km^2). These results are in contrast with Sallam et al., (2013)^[25], who reported that the very high risk area in Jazan region was 670.43 km^2 . 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 environmental, 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 diseases as 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 be the absence of mosquito classification to species level. In light of the shortcomings of this study, conducting more spatio-temporal studies should be considered in

future studies towards implementing more effective control measures against mosquito-borne diseases.

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