Assessment of past Rift Valley fever outbreak using Modeling, Risk analysis and decision tree in Sudan

mohamed E Ahmed (✉ mohamedalsadiq@cvrlsudan.gov.sd)
Central Veterinary Research Laboratory

Maximilian PO Baumann
Freie Universitat Berlin

Thomas Selhorst
Bundesinstitut fur Risikobewertung

Tamador M Abdellah
Central Veterinary Research Laboratory

Atif A Abdelgadir
University of Khartoum Faculty of Veterinary Medicine

Research

Keywords: RVF, disease modeling, risk analysis, decision tree, Sudan

DOI: https://doi.org/10.21203/rs.3.rs-27733/v1

License: ☇ .getOrElse(Read Full License)
Abstract

Background

A retrospective study was performed in selected states of the Sudan that include Gezira state, White Nile, Blue Nile, Khartoum, River Nile and Sennar states in order to determine the seroprevalence of Rift Valley Fever (RVF) and associated risk factors as well as an attempt was made to apply mapping, risk analysis tool to investigate the disease. Those epidemiological tools were used for purpose of good management strategies and policy makers as well. The source of data was epidemiological reports and archives from the Federal Ministry of Animal resources, universities and Non Governmental Organizations for outbreaks of RVF also and laboratory reports of serum samples tested by ELISA. The test performance characteristics were 99% test sensitivity and 99% test specificity. A total of 3393 from, sheep, goats and cattle were sampled and selected to be examined. Estimated Seroprevalence of RVF was 0.15% (n=905) in sheep, 0.20% (n=776) in goats and 0.13% (n=638) in cattle respectively. Also information gathered was used to determine the distribution of the disease, transmission and recovery rate of infection over point in time.

Method

This study was retrospective survey designed to investigate previous outbreaks of RVF. The method used was risk analysis, modeling and decision tree to explain the distribution of chronology of the disease.

Result

The current study was carried out quantitative risk analysis to investigate RVF. Risk analysis revealed that RVF is likely to occur in the Sudan, and vaccination was estimated with highest rollback to reduce the seroprevalence of RVF to be unlikely with expected value of $ US 4368789. A frequency of 0.12%, 0.12% and 0.1% from cattle, goats and sheep population were entered in SIR model respectively. The adjustable parameters were susceptible, infected, recovery rate and death rate; the result concluded that the curve of susceptible(S) was declining, infected(I) was increasing; while recovered(R) was increasing. A total of 2487 mosquitoes were pooled, represented by 600 mosquitoes in the final model, recovery rate of mosquito overtime was 0.22 which is statistically not significant, (P-value =0.9825), and rate of infection was 0.83%. In the current study, the Basic reproductive number (R0) was estimated by one. Uncertainty for RVF model was ranged between 0.01 to 610.65 with confidence of 95%. This study concluded that RVF is endemic in the Sudan.

Conclusion

Rift Valley Fever (RVF) is arthropod-borne viral zoonosis disease. It affects small ruminants, sheep and goats, and large ruminants like cattle and camel, and also can affect human. Rift Valley Fever virus (RVFV) belongs to the family Bunyviridae, genus Phlebovirus. The first isolation of RVFV was done in Kenya (4). RVFV is a negative sense RNA virus. RVFV genome is structured from three partites, small, medium and large. It is peracute or acute febrile disease that is characterized by numerous abortions in
female and high mortality among young animals and humans. Mosquito is the principle vector of the disease. It is transmitted by direct contact with infected tissues or organs of animals and ingestion of uncooked or raw milk (1). The study was carried out to investigate the risk related to RVF seroepidemiology and distribution of the disease among livestock and to determine the most efficient policies in management of RVF outbreak by using retrospective data, however more further serosurveillance were required to thoroughly understand the epidemiology of the disease.

Introduction

Rift Valley Fever (RVF) is arthropod-borne viral zoonosis disease. It affects small ruminants, sheep and goats, and large ruminants like cattle and camel, and also can affect human. Rift Valley Fever virus (RVFV) belongs to the family Bunyviridae, genus Phlebovirus. The first isolation of RVFV was done in Kenya (4). RVFV is a negative sense RNA virus. It is peracute or acute febrile disease that is characterized by numerous abortions in female and high mortality among young animals and humans. Mosquito is the principle vector of the disease. It is transmitted by direct contact with infected tissues or organs of animals and ingestion of uncooked or row milk (1).

Objectives

This paper is to understand epidemiology of Rift Valley fever in the study by using Risk analysis tools.

Materials And Methods

RVF statistical model

Statistical model was analyzed based on data and information given during RVF outbreak. Model for RVF was mathematical or compartment model which referred to S (susceptible), I (infected) and R (recovered) from the study population (Fig. 1). It is used to investigate the distribution of disease in the population. It has been built on SIR Model template adopted for influenza virus by (6). The parameters for host and vector models were obtained from literature (5),(15). The study assumed that population was homogenous. The model was comprised from a system of three coupled non-linear differential equations (Tables 1 and 2).

\[
\dot{S} = \beta SI \quad (1.1a) \\
\dot{I} = \beta SI\gamma I \quad (1.2b) \\
\dot{R} = \gamma I \quad (1.3c)
\]

Where, \( \dot{S} \) is susceptible, \( \dot{I} \) is infected and \( \dot{R} \) is recovered or and immunized individuals, \( \beta \) is transmission rate, \( \gamma \) is recovery rate and denote the derivatives with respective to time \( t \). \( N \) denotes for population size.
\[ N = S + I + R, \]
\[ \dot{N} = \dot{S} + \dot{I} + \dot{R} = 0 \]

Applying phase plane analysis to the equation set

\[ \dot{S} = \beta SI = 0, \quad (1.2a) \]
and \[ \dot{I} = \beta SI \gamma I = 0 \quad (1.2b) \]

therefore, S-nullclines were

\[ S = 0, \quad (1.3a) \]
\[ I = 0; \quad (1.3b) \]

and the I-nullclines were

\[ S = \frac{\gamma}{\beta}, (1.4a) \]
\[ I = 0 \quad (1.4b) \]

The three nullclines form a triangle with vertices \((0, 0)\), \((N, 0)\), and \((0, N)\) on the \(SI\) –plane. This triangle was invariant region of steady state. The trajectory always starts from the line \(S + I = N\), since \(R(0) = 0\). A point was an equilibrium point if and only if \(\dot{S} = \dot{I} = \dot{R} = 0\), thus any trajectory was converge to a point \((S, 0)\) where \(0 \leq S \leq N\).

If \(S(0) = S_0 < \frac{\gamma}{\beta}\), both \(S(t)\) and \(I(t)\) decreased and converged to a point on the S-axis; There is no outbreak. If \(S_0 > \frac{\gamma}{\beta}\), \(I(t)\) first increased in the region \((\frac{\gamma}{\beta}, I)\) and then decreased to 0; in this instance outbreak occurs. In conclusion, there was a threshold value \(\frac{\gamma}{\beta}\). Define as the basic reproduction number \((R_0)\).

\[ R_0 = N\beta \div \gamma \approx S_0\beta \div \gamma \quad (1.5) \]

Then

\[ S_0 > \frac{\gamma}{\beta} \leftrightarrow R_0 > 1, \quad (1.6) \]

and \[ S_0 < \frac{\gamma}{\beta} \leftrightarrow R_0 < 1, \quad (1.7) \]

If \(R_0 < 1\), RVF epidemic dies out, when \(R_0 > 1\) a RVF outbreak is possible, (17). The final model has been calculated by disease- euler-quad model which as follow

\[ R_0^* = r(n) + ((1-d)*r*I(n))*C + 0.5((1-d)*r*(k*S(n)*I(n)-r*I(n)))*C^2 \quad (1.7) \]
Where, $s(n)$ was susceptible, $I(n)$ was infected, $r(n)$ was recovered, $K$ was transmission rate, $r$ was recovery rate, $d$ was death rate, $C$ was constant
Table 1
Adjustable parameters of Rift Valley Fever model in ruminant

| Parameter* (adjusted) | Description | Symbol | Value | Reference |
|-----------------------|-------------|--------|-------|-----------|
| Susceptible           | Susceptible with RVF from animal sampled | (S0)   | 49990 | Estimated |
| Infected              | Infected with RVF from animal sampled | (I0)   | 10    | Estimated |
| Total in population   | population of study (ruminant) | (N)    | 50000 | Estimated |
| Transmission rate     | Transmission rate of RVF from S0 to I0 | (k)    | 0.000004 | Estimated |
| Recovery rate         | Recovery duration (year) | (R)    | 8/365 | (16) |
| Death rate            | Natural death rate in ruminant (year^-1) | (d)    | 1/5.7 | (18) |
| Total sick & not died | (Rfinal) | 16500 | Estimated |
| Total deaths          | (Tfinal) | 15000 | Estimated |
| Number never sick     | (Sfinal) | 33500 | Estimated |
| Max sick at one time  | (Imax) | 7000 | Estimated |
| Max prop(of S0)sick   | (ofS0) | 0.140028 | Estimated |
| Max prop(of N)sick    | Probability of infection in ruminants | (ofN)  | 0.14 | (19) |
| Mosquito infection rate | Proportion of infected mosquitoes from vertical transmission | |

*Parameters entered in SIR model were adjusted from different publications to understand the proportion of Suspected, Infected and Recovered livestock in relation to RVF. Also, it is estimated when there is no reference cited. These parameters were used to calculate the model to investigate the distribution of RVF among study population.
### Table 2
**Adjusted parameter for RVF vector model**

| Parameter* (adjusted) | Description                                                                 | Symbol | Value       | Reference |
|-----------------------|-----------------------------------------------------------------------------|--------|-------------|-----------|
| Mosquito infection rate | Proportion of infected mosquito from vertical transmission                 | (k)    | 0.000005    | (20)      |
| Recovery rate         | Mosquito recovery rate from RVF infection                                    | (r)    | 0.021918    | Estimated |
| Death rate            | Death rate of mosquito due RVF                                              | (d)    | 63.84       | (21)      |
| Susceptible           | RVF susceptible mosquito population                                         | (S0)   | 59990       | Estimated |
| Infected              | Infected population of mosquitoes by RVF                                   | (I0)   | 10          | Estimated |
| Total population      | Total population of mosquitoes                                              | (N)    | 2487        | Estimated |

This parameter were used to calculate the model for Mosquito vector and understand the distribution and circulation of the virus among vector of the disease, and can be used to generate models for infectious disease.
Table 3
Rift Valley Fever risk groups and risk assessment and management

| RVF Risk group (category) | RVF (risk assessment & management) |
|---------------------------|-----------------------------------|
| Risk                      | Likelihood                         | Impact                             | Risk score                      | Treatment/action                                        |
| RVF incidence (index case)| 33.3% probability to produce secondary case | Presence of IgM Abs in free area | Acceptable level of risk e.g. development of a RVF foci | Treatment of infected cases or and / quarantine of index case |
| RVF foci                  | 33.3% probability to produce an outbreak | Presence of IgM&IgG Abs in endemic area | Unacceptable level of risk e.g. development of RVF outbreak | Buffer vaccination around a foci or/and restricted movement |
| RVF outbreak              | 33.3% probability to produce a pandemic | Presence of IgM&IgG Abs both in free and endemic areas | Unacceptable level of risk e.g. spread of RVF through trade route | Official notification & reporting of disease status, vaccination, vector control, quarantine and trade ban |

Statistical analysis

Mathematical or statistical model was adopted by using SIR model used in Microsoft Excel, version 2007 and Decision tree were analyzed by Solution tree version.

Results

SIR Model in host

A total of 50000 hosts were entered in SIR model over time, to explain the trend of the disease. Population structure was 58.8% susceptible, 3.9% infected and 37.3% recovered. The model was found that at 0.18% of the herd seroprevalence of sheep flocks has shown only one positive case could be detected in order to consider that the herd was positive for RVF, While at 0.56% herd seroprevalence of goat flocks only one positive case could be detected in order to consider that the herd was positive for RVF and at 0.73% herd seroprevalence of cattle only one positive case could be detected in order to consider the herd was positive for Rift Valley Fever (Figs. 2, 3 and 4).

A 0.12% of cattle populations were enforced in the model. The adjustable parameters for the final model were 49990 susceptible, 10 infected for 50,000 animal hosts, 0.000004 was transmission rate, 0.021918 was recovery rate and 0.3 death rate. The curve of susceptible population were declining at 500000, curve for infected were increasing and reached the peak at 30500, while recovered had gotten plateau at 40000 (Fig. 2). The sheep populations were 50390000, and the goat populations were 42756000 with density of
20.11 and 17.06 respectively. A 0.1 and 0.12% from sheep and goats were entered in RVF Model, respectively. The parameters were a susceptible (S₀), 49,990 susceptible, 10 infected for 50,000, 0.000004 transmission rates, 0.02 recovery rates and 0.03 death rates. The curve for susceptible sheep and goat were declining at 30,500, curve for infected were reached 20,500, whereas recover get plateau at 50,000 (Fig. 3and 4).

Vector model

This study had revealed that Mosquito as a principle vector to transmit RVF in the Sudan, *Aedes* spp was a primary vector to cause RVF according to its biology which renders RVFV to survive for longer period during dry season in Dambos “land depression”. This feature (transovarian transmission) was to preserve RVFV in mosquito’s egg; when flooding comes, infected eggs hatch and flare up and disseminate RVFV to susceptible population depending on mosquitoes vector density. *Culex* spp has found to have a secondary role in transmission of RVFV in the Study area from 1973 to 2007 (Table 2).

A total of 60,000 sample of mosquitoes were entered in SIR model after pooling with 95% confidence limit (CL), transmission rate was 0.000005, death rate was 63.8% and RVF recovery rate of mosquito was 0.02 (Fig. 5), (Table 4).

Vector Model is referred to suspected (s) is decreasing at 30 individual, infected(I) was increasing at 50 individual and recovered (R) was increasing at 95 individual with 100 time iteration. This was development of epidemic curve in vector at a point in time. This to explain distribution of RVFV in mosquito vector population by dividing it into three parts.

| Country | RVF outbreak | Vector | Reference |
|---------|--------------|--------|-----------|
| Sudan   | 1973         | Culex spp, Aedes spp | (25), (26) |
|         | 1997 to 1998 | Not defined | (27), (28) |
|         | 2003 to 2006 | Not defined | (27), (28) |
|         | 2007 to 2008 | Aedes spp, Culex spp | (29), (30) |

*Parameters entered in Vector Model were adjusted from different publications to understand the proportion of Suspected, Infected and Recovered Mosquito vector in relation to RVF. Also, it is estimated when there is no reference cited.*

Decision tree model

The current study has built model for RVF control measures by solution tree with 21 nodes, total probability of 31% and expected value of $78,774,726.09. Four decision branches, sixteen chance branches and twelve end points had been produced. Assumptions for the scenario had been analyzed with 0.5% Probability or likelihood distribution with 95% confidence. The expected or pay off value of
vaccination, vector control and expert opinions were estimated by $78,774,726, $7,217,056 and $24,056,798, respectively. The model has resulted in 37.5% chance of success for vaccination, whereas vector control and expert opinion have 18.75% chance of success as countermeasures for RVF outbreak. Vaccination was estimated with highest rollback value of $69,900,624. It has resulted in decreasing of RVF prevalence to be unlikely or negligible with expected value of $4368789 (Fig. 6).

Uncertainty analysis of RVF model

Uncertainty was analyzed to estimate the fitness of RVF model with 95% confidence interval (CI) to simulate the occurrence of the disease in the real life. Uncertainty for RVF Model was ranged between 0.01 to 610.65 with confidence of 95%. Five parameters were entered and analyzed in the model for sheep, goats, cattle and vector. Uncertainty for average of contact were 124.65, susceptible was 610.65, infected were 401.94, while uncertainty for duration of infectionness was 0.72. Lower quantile for susceptible, infected, transmissibility, rate of contact and duration of infectionness were estimated by 152.6, 100.4, 0.002, 31.1, 0.18, while upper quantile were estimated by 457.9, 301.4, 0.006, 93.4 and 0.54 respectively. Also, uncertainty was estimated by measuring homogeneity and representativeness, of parameters taken against day of time (Fig. 7).

Discussion

In this study, SIR Model had analyzed dynamic and epidemiology of RVF in study population. The populations at risk were estimated over 30,000 heads for sheep, goat and cattle, whereas study host was more exposed to RVFV (Fig. 2, 3 and 4), with uncertainty analysis that ranges from 0.01 to 610.65, with confidence of 95%, although there is lack of information and data available for the disease during study, which is important to know the dynamics of the disease when it occurs. Clustering had been reported in Gизera state, where foci or pockets of the disease were present; this had come into agreement with research done by (8), where clustering can estimate the incidence of RVF in study area for a certain period of time which provides understanding for the spatial distribution and epidemiology of RVF. Frequency of annual temperature and annual rain fall were been analyzed to understand its relationship with RVF outbreaks in study area. Environmental risk factors like ElNioSouthern Oscillation, Average Annual precipitation and Elevation Map had significant and important role to play as predisposing factors to occurrence of RVF by increasing of rainfall which improve multiplication of RVF insect vectors to disseminate the virus to susceptible hosts. Studying the climate and ecosystem, RVF was found to be correlated with weather anamolies and Elino phenomenon in Eastern Africa by (22), which was leading to up-average rainfalls that prefer replication and increased mosquito density. This has important role in transmission cycle of RVFV to exposed host, when the virus can survive in egg of pregnant mosquitoes which could be dormant in dambos or land depression for long peroid of time specially in interepidemic peroid and when rainfall come, it flared up and disseminated the virus to suspected hosts, this is has been significantly important observation in East of Africa. Also, it had explained that parameters of deterministic models (2) is analyzing the multiplication rate of the disease and rate of infection in a given geographical zone. Vector model had analyzed more than 80% of mosquito to carry RVFV to the vector,
given that susceptible hosts were exposed to the vector, RVF outbreak is likely to occur with 95% confidence. In addition, entomological survey had shown that *Aedes vexans* and *Culex quinquefasciatus* were positive to RVF virus (13). Therefore, epidemiological model for RVF in this study was carried out analysis of SIR model, vector model, spatial mapping model and risk factors associated with RVF seroprevalence. Epidemiological model for this study had manifested probability distribution of RVF on study population and different degree of statistical differences and association for host population, environmental risk factors with RVF seroprevalence, this agreed with the effect of environmental risk factors and disease dynamics on population by(23), whereas models is build up on availability of information and report about the disease; Although it is also important to improve the knowledge about disease by analyzing available information by using disease models. RVF is mainly endemic in Africa and these are involving several regions and countries in the same time. Also, it had occurred outside African continent in Arabian Peninsula and some Indian Ocean islands. It was associated with periodic cycle and heavy rain falls and flooding which usually occurred after interval which prefers mosquito proliferation. RVFV was first reported in Sub-Saharan Africa and southern Africa (3). Although the virus had been found outside Sub-Saharan Africa to Egypt (Gerdes,2004), Saudi Arabia and Yemen (24). In 1973, RVF outbreak was erupted in Southern Africa where human deaths were reported (12). A 958 human causalities in 1977 and 200 human deaths in 1978 were occurred due RVF epidemic in Egypt. In Kenya and Somalia, RVF caused 478 human deaths in 1997(14). In 2000, RVF outbreak was confirmed in Saudi Arabia and Yemen with 882 confirmed cases and 124 deaths (11). In the Sudan, serological evidence of RVF was reported in 1936 which revealed 6.7% of 164 human sera by using precipitating antibodies (7). In addition, reporting of cases of RVF, diagnosis and treatment capability and raising awareness of the disease epidemiology, training of medical cadres and research and development is importantly significant to exceed the planning and policy to contingency and preparedness against RVF and reducing its spreading in suspected countries.

**Conclusion**

Rift Valley Fever (RVF) is arthropod-borne viral zoonosis disease. It affects small ruminants, sheep and goats, and large ruminants like cattle and camel, and also can affect human. Rift Valley Fever virus (RVFV) belongs to the family *Bunyviridae*, genus *Phlebovirus*. The first isolation of RVFV was done in Kenya (4). RVFV is a negative sense RNA virus. RVFV genome is structured from three partites, small, medium and large. It is peracute or acute febrile disease that is characterized by numerous abortions in female and high mortality among young animals and humans. Mosquitoe is the principle vector of the disease. It is transmitted by direct contact with infected tissues or organs of animals and ingestion of uncooked or row milk (1). The study was carried out to investigate the risk related to RVF seroepidemiology and distribution of the disease among livestock and to determine the most efficient policies in management of RVF outbreak by using retrospective data, however more further serosurveillances were required to thoroughly understand the epidemiology of the disease.

**Abbreviation**
Declarations

This to declare that this research work is to fulfill partial requirement of doctoral degree

Ethical Approval and Consent to participate

It is not in human data (retrospectively registered)

Consent for publication

All authors have agreed to publish this manuscript

Availability of data and materials

Yes

Competing interests

There is no conflict of interest from any of authors of this manuscript

Funding

Ministry of science and Technology had been chosen as funder from the list

Authors’ contributions
The manuscript is written and statistically analyzed by Mohammed E. Ahmed¹, Maximilian the project coordinated by PO Baumann² the statistical analysis was revisioned by Thomas Selhorst³ the bench work and data availability for project was supplied by Tamador M. Abdellah¹.² The manuscript was revision and designed for writing by, Atif A. Abdelgadir⁴

Acknowledgements

the authors of article would like to acknowledge the Director of Central Veterinary Research laboratory for permission to publish this research.

Authors' information

1 Central Veterinary Research Laboratory, Rift Valley fever unit, Sudan 2 Freie univeristaet-Berlin, Fachberich Veterinarmedizin, FAO Reference Center for public health, Germany 3 Bundesinstitut fur Riskiobewertung, Berlin, Germany 4 Central Veterinary Research laboratory, Viral vaccine production department, Sudan 5 University of Khartoum, Faculty of Veterinary Medicine, Department of Veterinary preventive medicine and public health, Sudan

References

1. Adam A. Manifestations of severe Rift Valley Fever in Sudan. Int .J. infect. Dis 2010, (14): 179–180.
2. Chalom A, Prado,p. Uncertainty analysis and composite hypothesis under the likelihood paradigm,. Q-bio.QM 2015.
3. Daubney R, Hudson JR, Gamham PC.. Enzootic hepatitis or Rift Valley Fever.An undescribed virus disease of sheep, cattle and man from East Africa. J. Pathol. Bacteriol 1931, (34): 545–579.
4. Daubney R, Hudson JR. Rift Valley Fever. The Lancet J,1932 (1): 611–612.
5. Farida Chamchod., Cosner RStephenCChris., Ali N, Hassan. JCBieer. Shigui Ruan. A modeling approach to investigate Epizootic outbreaks and Enzootic Maintenance of Rift Valley Fever virus. Bull Math Biol 2014 (76):2052–2072.
6. Findlater A. http://archives.aidanfindlater.com/blog/2010/04/20/the-basic-sir-model-in-r/. Retrieved 5 18, 2018, from http://rstudio-pubs-
static.s3.amazonaws.com/6852_c59c5a2e8ea3456abbeb017185de603e.html.
7. Findlay G, Stefanopoulo GJ, Macclum FO.. Presence d’anticorps contre la fievre de la Valle du Rift dans le sang des Africans. Bull .soc. Pathol. Exot 1936, (29):986–996.
8. Gadha S. A retrospective analysis of the epidemiology of Rift Valley Fever in Namibia. dissertation submitted to the Department of Veterinary Tropical Disease, Faculty of Veterinary Science University of Pretoria in Partial fulfillment of the requirement for degree of Msc(Animal/Human/Ecosystem Health)2015.
9. Gerdes G, Rift Valley, Fever. RevScitechOffintEpiz. 2004;23(2):613–23.
10. Matthew JK, Pejman R. Modeling Infectious Diseases in Humans and Animals. Princeton University Press. 2008.

11. Mohamed A, Ashshi AM, Asghar AH, Abd El-Rahim IHA, El-Shemi AG & T.Zafar. Seroepidemiological survey on Rift Valley fever among small ruminants and their close human contacts in Makkah, Saudi Arabia, in 2011. Rev.Sci.tech.Off.int.Epiz 2014, (3):33.

12. Peters CJ, Linthicum kL. Handbook of Zoonoses. (2nd edition) CRC Press 1994.

13. Rania A, Emadeldin HK, Amin E. E. R.. Rift Valley Fever Virus (RVFv) Dissemination inside Mosquitoes and Investigation of the Influence of Climate on Mosquitoes Abundance. J Entomol Zool Stud. 2013;1(5):1–9.

14. WHO. Rift Valley Fever outbreak in East Africa. Atlanta, USA: International Conference on Emerging Infectious Disease 1998.

15. Linthicum K, Davies FG, Kairo A, Bailey C. Rift Valley Fever virus (family Bunyaviridae, genus Phlebovirus). Isolations from Diptera collected during an inter-epizootic period in Kenya. J Hyg 1985, (95): 197.

16. Pepin M, Bouloy M, Bird ,BH, Kemp A, Paweska J. (2010). Rift Valley Fever virus (Bunyaviridae:Phlebovirus): an update on pathogenesis, molecular epidemiology, vectors, diagnostics and prevention. Vet. Res 2010, (61): 41.

17. Diekmann O, Heesterbeek JAP. Mathematical epidemiology of infectious diseases: Model. New York: John Wiley & Sons, Ltd.; 2000.

18. Majok M, Zessin KH, Baumann MPO.. Analyses of baseline survey data on rinderpest in Bahr el-Ghazal Province, with proposal of an improved vaccination strategy against rinderpest for southern Sudan. Trop Anim Health Prod, 1991 (23): 186–196.

19. Turell M, Linthicum KJ, Patrican LA, Davies FG, Kairo A, Bailey. C I.. Vector competence of selected African mosquito (Diptera:Culicidae) species for Rift Valley Fever virus. J Med Entomol ,2008 (45): 102–108.

20. Freier J, Rosen L. Vertical transmission of dengue virus by the mosquitoes of the Aedes scutellaris group. Am J.Trop. Med. Hyg 2014, (37): 640–647.

21. Mpeshe SC, Haario H, Tchuenche JM. A mathematical model of Rift Valley Fever with human host. Acta. Biotheo 2011, (59): 231–250.

22. Mroz C, Gwida M, El-Ashker M, El-Diasty M, El-Beskawy M, Ziegler U, Eiden M, Martin H, Groschup. Seroprevalence of Rift Valley fever virus in livestock during inter-epidemic period in Egypt, 2014/15. BMC Vet Res. 2017;2017::13. (87).

23. Matthew JK, Pejman R. (2008). Modeling Infectious Diseases in Humans and Animals. Princeton University Press.2008.

24. Jupp kemp,A, Grobbelaar A. The 2000 epidemic of Rift Valley fever in Saudi Arabia: Mosquito vector studies. Med Vet entomol 2000, (16): 245–52.
25. Bobbie ImadeldinA, Erickson. R, Rehab M, Elageb., Marina L, Khristova SA, Carroll., Isam M, Elkhidir., Mubarak EKarsany. Abdelrahim EKarrar., Mustafa I Elbashir and Stuart T.Nichol.. Rift Valley Fever, Sudan ,2007 and 2010. *Emerg Infect Dis*, 2013 (19): 246–253.

26. Kowther Mohamed Saeed Ahmed., Amna Ahmed Hamid., Abbas Doka.. Investigation of Spatial risk factors for RVF disease occurrence using remote sensing & GIS -A case study: Sinnar state, Sudan. Journal of Geopraphic Information System 2015, (7): 226–257.

27. CDC. Rift Valley Fever outbreak-Kenya, November 2006-January2007. MMWR Morb Mortal Wkly Rep 2007, pp. 56–73.

28. Yousif EH, Eliningaya JK, Mostafa MM, Amin E, E.R and Johnson OO. (2014). Recent outbreak of Rift Valley Fever in East Africa and the Middle East. f.p.u.b.h 2014(169). :2.

29. Wilson W. Rift Valley Fever viurs ecology and the epidemiology of disease emergence. *Ann N Y Acad 1994*, 169–180.

30. Osama A, Clas A, Rosemary S, Magnus E. The 2007 Rift Valley Fever outbreak in Sudan. PloS Negl Trop Dis. 2011;5(9):1229.

**Figures**
Figure 1

SIR Model represents Susceptible, Infected and Recovered compartments of study population with infection and recovery rates. The explain the distribution of RVF among study population by dividing it into three parts
Figure 2

SIR Model for RVF in Cattle population in Sudan from 1973 to 2007. SIR Model is referred to as suspected(S) was decreasing at 95 individual, infected(I) was increasing at 80 individual and Recovered(R) was in increasing with continuous growth at 200 individual with 100 times (iteration) multiplication. Also this to explain the distribution and trend of RVF in population by dividing it three parts.
Figure 3

SIR Model for RVF in sheep population in Sudan from 1973 to 2007. SIR Model is referred to as suspected(S) was decreasing at 90 individual, infected (I) was increasing at 85 individual and Recovered (R) in increasing at 195 at 100 time (iteration) multiplication . This was development of point curve of RVF, when it occurred at point in time. The figure was illustrating the Susceptible, Infected and Recovered model for Rift Valley fever in animal population over time and their percentages were 58.8%, 3.9% and 37.3% respectively. This means to simulate the rate of occurrence of RVF to understand the occurrence in real life. Also this to explain the distribution and trend of RVF in population by dividing it to three parts.
SIR Model: Goats

Figure 4

SIR Model for RVF in goat’s population in Sudan from 1973 to 2007. SIR model is referred to as Susceptible, Infected and Recovered for goats population. Susceptible was decreasing, infected was increasing and Recovered was increasing for 70 days. It represents the basic SIR model for an epidemic at a time. Also this to explain the distribution and trend of RVF in population by dividing it into three parts.
Figure 5

Vector model. Vector Model is referred to suspected (s) is decreasing at 30 individual, infected(I) was increasing at 50 individual and recovered (R) was increasing at 95 individual with 100 time iteration. This was development of epidemic curve in vector at a point in time. This to explain distribution of RVFV in mosquito vector population by dividing it into three parts.
Figure 6

Decision tree model for RVF outbreak explaining probability and expected values of branches and cost-effectiveness for RVF control. Decision tree has explained the probability distribution from the nodes and branches of decision analysis of three options to control RVF which are vaccination, vector control and expert opinions to estimate what is more rational path to be considered. This method is one of the decision supporting tools that have role in policy for prevention and control of infectious diseases. This diagram explains also the percentage of most important tool for control of RVF with less economic cost.
Uncertainty analysis for SIR model. Uncertainty was obtained by estimating the standard error (SE) of sample (SE mean was 26.6 for suspected, 139.3 for rate of contact and 0.15 for duration of infectionness) with 95% confidence interval. It was measuring the degree of goodness of fit for the model with optimization of assumed parameters to be simulated at SIR model. This analysis is to investigate the accuracy of disease model that has been studied in this research.

Figure 7