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Using geographic information system and remote sensing to study common mosquito-borne diseases in Saudi Arabia: A review

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Abstract

Mosquito-borne diseases have spatial and temporal patterns, because mosquito density and longevity are based on a number of factors, such as temperature, precipitation and mosquito breeding habitats. Geographic Information System (GIS) and Remote Sensing (RS) and their related tools for mapping and modeling provide new and expanding opportunities for mosquito-borne diseases (MBD) research because they can display and model the temporal and spatial relationships between causes and diseases.

Key words: Geographic Information Systems, Remote Sensing, mosquito-borne diseases, modeling, mapping.

Introduction

Mosquito-borne diseases are carried by different mosquito species. Each mosquito species lives in a specific habitat and transmits a variety of diseases [1]. The most common species are the *Anopheles* mosquito that transmits malaria and filariasis, the *Aedes* mosquito that transmits dengue, yellow fever, and Rift Valley fever, and the *Culex* mosquito that transmits filariasis and the encephalitis virus [2]. There is a prevalence of mosquito-borne diseases in more than 100 countries, and significantly, they infect 700 million people and cause about 3 million deaths every year [3].

Although there are some studies of MBDs, especially malaria, Rift Valley and dengue fever in Saudi Arabia, there is still a need to examine, systemically, the suitability of applying GIS, RS and spatial analysis tools in MBD research in Saudi Arabia. The review presented here aims to describe the strengths and limitations of GIS, RS and spatial analysis tools, and to make recommendations for further applications of GIS, RS and spatial analysis in MBD research in Saudi Arabia.

Materials and Methods

Multiple online databases were used to extract different types of articles, academic papers, theses, and other documents that relate to the common mosquito-borne diseases in Saudi Arabia (malaria, Rift Valley fever and dengue fever). These databases were ABS Statistics, BioOne, CSA, Current Contents, Emerald, Gale databases, Hein online, Informit, JSTOR, Science Direct, Scopus, SpringerLink, Taylor and Francis, Web of Knowledge, and Google Scholar. The literature search included the use of differently combined key words to search each of the above databases: vector-borne diseases and GIS, GIS and dengue, remote sensing and dengue, *Aedes* and modeling, *Aedes* and mapping, mapping and vector-borne diseases, mapping and malaria, spatial and dengue, space-time and vector borne, GIS and diseases, remote sensing and infectious diseases, Lyme and GIS, West Nile virus and GIS, filariasis and GIS, climate change and VBDs, environmental parameters and VBDs, VBDs and Saudi Arabia, MBDs and Saudi Arabia, Asir and malaria, Gizan and malaria, Jeddah and dengue fever, Makkah and dengue fever, and Gizan and Rift Valley.

Results

The results of the search represent hundreds of articles and documents that are related to vector-borne diseases and mosquito-borne diseases worldwide. The number of published common MBD articles related to Saudi Arabia was 108. Of all articles collected about Saudi Arabia, 58% were related to malaria research; others were related to Rift Valley fever (27%) and dengue fever (15%) (Fig. 1). A number of interesting trends have emerged from the analysis. Figs 2-4 show the distributions of articles, relevant to malaria, Rift Valley and dengue fever, by year. There was an increase in the study of malaria in medical research between 1967 and 2002, while between 2003 and 2010 there has been a decrease in the study of malaria in medical research (Fig. 2). Fig. 3 shows that 35% of the rift valley publications were in 2000, because there was a major outbreak of the disease in that year. After that, there have been fluctuating trends in the publications between 2002 and 2006; and from 2006 to 2010, there was no change in the number of publications. Fig. 4 indicates that 69% of dengue fever publications were from 2008 to 2010 while 31% of the publications were between 1997 and 2007.

Most publications that studied common mosquito-borne diseases in Saudi Arabia have been published in specific journals.

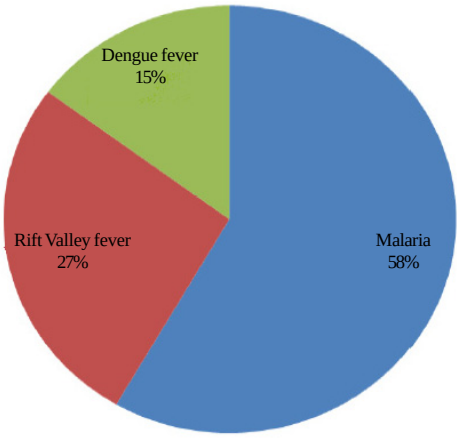

Figure 1. Percentage of published articles of common MBDs in Saudi Arabia.

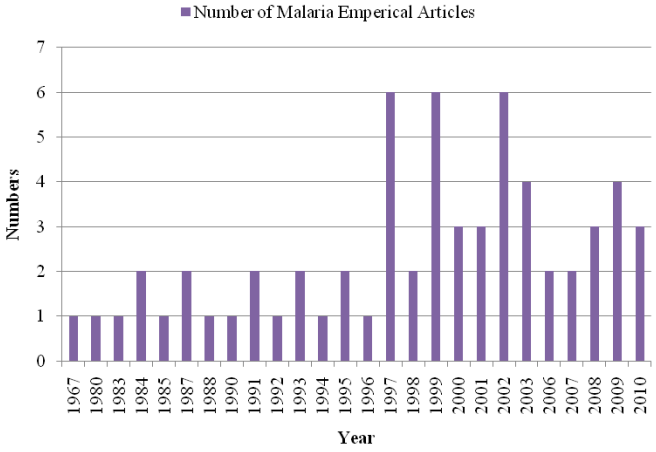

Figure 2. Trends of publications on malaria in Saudi Arabia.

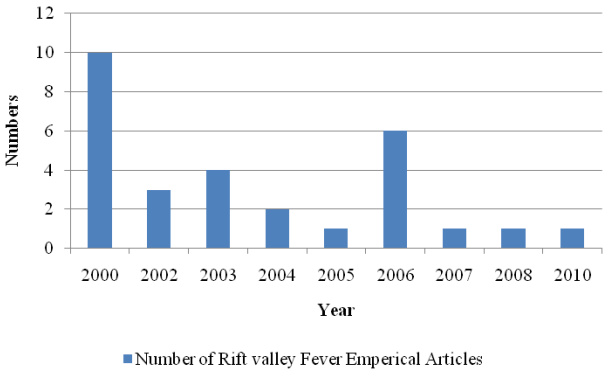

Figure 3. Trends of Publications on Rift Valley fever in Saudi Arabia.

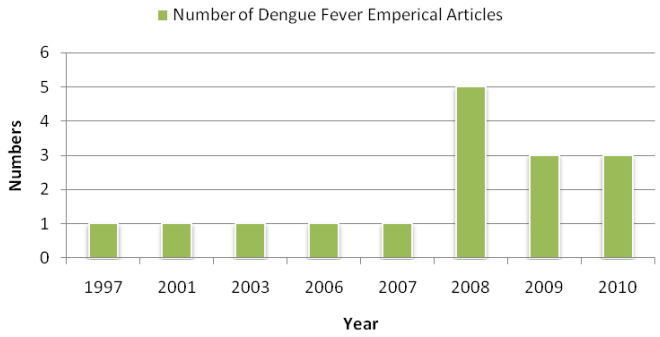

Figure 4. Trends of publications on dengue fever in Saudi Arabia.

The Annals of Saudi Medicine, the Journal of the Egyptian Society of Parasitology and the Saudi Medical Journal contained the most malaria-related articles (59%). Emerging Infectious Diseases, Revue Scientifique ET Technique-Office International Des Epizooties, Clinical Infectious Diseases, the Journal of the American Medical Association and Morbidity and the Mortality Weekly Report were the most common vehicles for articles related to Rift Valley fever (52%). Dengue fever publications have no specific journal(s) that is a most common vehicle for their related articles. Additionally, the search resulted in locating one paper about using GIS to visualize the effective distribution of vector population surveillance devices in Jeddah [4]; it was presented in the second national GIS symposium in Saudi Arabia. Another study, not published, investigated the Rift Valley fever outbreak in the Gizan region in 2005. The study provides a geographical contribution to understanding the prevalence of rift valley fever, using Geographic Information System and remotely sensed data [5].

Discussion

A number of major findings have arisen from this study. Firstly, GIS, RS and other spatial tools have not been widely utilized to study mosquito-borne diseases in Saudi Arabia. Secondly, the majority of the papers with a focus on MBDs have been related to malaria, indicating a growing awareness among this research community of the importance of varying diagnostic forms, effective medicines and clinical studies regarding malaria. Thirdly, the majority of the papers indicated limited awareness about the importance of varying forms of GIS, RS and other spatial analysis tools available to the mosquito-borne diseases research community in Saudi Arabia. Fourthly, socio-economic, climatic and environmental factors have not been widely used together to study mosquito-borne diseases in the World, and especially in Saudi Arabia. Finally, journals across the globe are acknowledging and promoting the use of GIS, RS and spatial tools to study MBDs.

According to the published articles, three common mosquito-borne diseases are endemic in different areas of Saudi Arabia. The following sections are examples of how the MBD research community studied malaria, Rift Valley fever and dengue fever in Saudi Arabia.

Malaria: According to the literature, the Southern part of Saudi Arabia is the epidemic area for malaria, with the highest number of cases (38,613 from 1997 to 2002) being reported from Gizan and Asir regions. The second area known for malaria is the western part of Saudi Arabia with 12,984 cases reported from the Al Taif, Makkah, Jeddah, Al Gonphoda and Theriban regions. The third area with a prominent number of malaria cases is Al Baha, with 2,148 cases reported between 1997 and 2002. The eastern part of Saudi Arabia is the oldest area of malaria endemic. King Fahad Hospital of the University (KFHU) reported malaria cases, especially in 1992 and between 1994 and 1998, 602 patients fulfilled the criteria for diagnosis during that period.

There were approximately 63 clinical and medical studies of the endemic malaria. For instance, Bashawri *et al.* [6] studied the epidemiological profile of malaria in a university hospital in the eastern region. The study showed that, in 602 cases, the mean age was from 14.3 to 25.8 and less than half of the cases were Saudis (42%). Of the cases 40% were diagnosed through February, March and September and *Plasmodium falciparum* and

Plasmodium vivax were the most common species.

Banzal *et al.* [7] described the clinical pattern and complications of severe malaria in Gizan. They analyzed the medical records of all malaria cases from 1995 to 1997. The results showed that the total number of patients during that period was 246, 154 males and 92 females, 210 were Saudis and 36 were non-Saudis. The age of the patients ranged from 8 months to 90 years, and 70.2% were less than 30 years old.

Malik *et al.* [8] studied, retrospectively, the malaria cases in the Asir central hospital. The study showed that 282 of malaria cases (84.4%) were Saudis and the majority (72.2%) were living in the lowlands of Tihama. Transmission was found to occur throughout the year, with peaks following the rainy season and in the summer season. In Saudis, *falciparum* malaria is more common than *vivax* (97.2% vs. 2.8%), while *vivax* malaria is more commonly seen in expatriates (46.2%). Poor response of *falciparum* malaria to chloroquine was more prevalent in expatriates than in Saudis (46.4% vs. 23%).

Rift Valley fever (RVF): Rift Valley fever cases are distributed in the Gizan, Makah, Asir, Riyadh, Eastern and Najran regions. Gizan and Asir reported the highest number of infected cases, especially in the first appearance in 2000. There are approximately 29 studies pertaining to Rift Valley fever in Saudi Arabia. Most of these studies concentrated on clarifying the prevalence and presence of these diseases among animals, studying the disease clinically and in the laboratory.

For example, Al-Qabati and Al-Afaleq [9] clarified the presence and prevalence of the disease among domestic ruminants in al-Hasa Oasis. They collected 598 serum samples from sheep, goats, cattle and camels during 2007. The low intra-herd prevalence, the scattered distribution of the two seropositives, the absence of anti-RVF IgM antibody and the absence of RVF-incidence in the sentinel herd suggested that the seropositive animals were infected from outside of the oasis rather than from an internal oasis infection. The study represented that outbreak of rift valley fever in the region was possible.

Madani *et al.* [10] studied a total of 886 reported cases of Rift Valley fever. From the 834 cases for which laboratory results were available, they found that 81.9% of the reported cases were laboratory confirmed, of which 51.1% were positive for only RVF immunoglobulin M, 35.7% were positive for only RVF antigen, and 13.2% were positive for both. They found that the mean age of those infected was between 19.4 and 46.9 years and that the ratio of male to female patients was 4:1. Clinical and laboratory features included elevated liver enzyme levels (98%), fever (92.6% of patients), elevated lactate dehydrogenase levels (60.2%), nausea (59.4%), vomiting (52.6%), leukopenia (39.7%), thrombo- cytopenia (38.4%), abdominal pain (38.0%), renal impairment or failure (27.8%), elevated creatine kinase levels (27.3%), diarrheal (22.1%), jaundice (18.1%), neurological manifestations (17.1%), severe anaemia (15.1%), hemorrhagic manifestations (7.1%) and vision loss or scotomas (1.5%). The mortality rate was 13.9%. Bleeding, neurological manifestations, and jaundice were independently associated with a high mortality rate. Patients with leukopenia had a significantly lower mortality rate than did those with a normal or high leukocyte count (2.3% vs. 27.9%; odds ratio, 0.09; 95% confidence interval, 0.01-0.63).

Dengue fever: In Saudi Arabia, few studies have been published about dengue fever, especially after its epidemic in 2005, 59% of them were published between 2008 and 2010. Most of the studies used methods that determined demographic, clinical or laboratory profiles [11] and predicted vector populations [12-14]. An epidemic of DF-like disease appeared in the Arabian Peninsula in the late 18th century and the disease was described in Zanzibar, Dar es Salam, the East African coast, Aden, Makkah and Jeddah [15]. The first appearance of DF in Jeddah was in 1994 with 289 confirmed cases. According to Fakeeh and Zaki [16], a total of 1,020 suspected clinical cases were examined by laboratory methods from February 1994-December 2002. Dengue virus infection was confirmed in 319 (31.3%) cases, 209 by virus isolation and the rest by serological techniques. DEN-2, DEN-1 and DEN-3 were detected between 1994 and 2002 in that order of frequency. Using IgG immunofluorescent assay or the haemagglutination-inhibition (HI) test, the prevalence of dengue reactive antibodies in the suspected group was confirmed in 515 (50.5%) of the 1,020 samples tested. A field survey from house to house had been done by the Department of Pest Control and Public Health of Jeddah Municipality [17]. Aljawi *et al.*[17] found that the fibre-glass drums of a total of 107 houses searched for *Aedes* breeding were suitable environments for breeding in Jeddah.

Al-Ghamdi *et al.* [12] studied the relationship between *Aedes* mosquito abundance, dengue fever cases and relative humidity in the western region of Saudi Arabia. They found a strong association between the humidity and the abundance of *Aedes* mosquitoes. Also, Al-Ghamdi *et al.* [18] assessed the larvicidal activity of five insecticides against *Aedes aegypti* using the WHO standard susceptibility tests.

El-Badry and Al-Ali [13] studied the prevalence and seasonal distribution of *Aedes* mosquito species in Al-Madinah Al-Munawwarah. They used black hole UV traps producing CO_2 overnight and the knockdown spray-sheet method in the morning to collect adults for a year, from July 2008 to June 2009, by standardised sampling. The study indicated that *Aedes aegypti* was the only identified *Aedes* mosquito species in all surveyed residential areas in Al-Madinah. A total of 463 *Aedes aegypti* adult mosquitoes were identified; 300 (64.8%) were females and 163 (35.2%) were males. Prevalence was abundant year-round with varying density among months, peaking in April. The density of *Aedes aegypti* in intra-domiciliary areas was higher than in extra-domiciliary stations, with a greater proportion of female mosquitoes. Non-fed females significantly outnumbered blood-fed females. These results necessitate further epidemiological surveillance and highlight the need for regular strict monitoring of *Aedes aegypti* in Al-Madinah Al-Munawwarah, to prevent the possibility of *Aedes aegypti* establishment in Al-Madinah.

Conclusions

This study found that many MBD studies have been conducted in Saudi Arabia and most of them explored the disease's clinical, laboratory and insecticide profiles. Using GIS and RS to study MBDs in Saudi Arabia was introduced in 2005, when Aldosari used them to investigate an outbreak of Rift Valley fever. Therefore, GIS, RS and their applications to MBDs are still in their infancy. This study also highlights the knowledge gaps in this area of research, especially in Saudi Arabia:

1. GIS and RS have not been utilized widely in Saudi Arabia, especially to study MBDs.

2. The quantitative relationships between environmental, socio-economic and climatic variables and the transmission of MBDs, especially DF, remain unclear. Further study is needed.
3. Spatial and temporal variation of DF, RVF and malaria needs to be evaluated in Saudi Arabia.
4. Most of MBD studies in Saudi Arabia have been concerned with clinical and laboratory profiles and they have not taken into account the spatio-temporal features of the diseases.
5. Spatio-temporal models using environmental factors (e.g. vegetation cover, soil types), socio-economic factors (e.g. income, sex, age) and climatic factors (e.g. temperature, humidity, and rainfall) have not been formally attempted.
6. Productive models for manipulation of GIS, RS and applications of spatio-temporal analytic methods are yet to be developed for the surveillance and control of mosquito-borne diseases, especially DF.

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