CHAPTER 1: INTRODUCTION AND BACKGROUND

1.1 Introduction

In recent decades, the global prevalence of dengue fever (DF) has grown dramatically. The disease is now endemic in more than 100 countries (Figure 1.1) (Gubler, 1995; WHO, 2012). Southeast Asia and the Western Pacific are the most seriously affected (WHO, 2002). According to WHO (2002), only nine countries had experienced DF epidemics before 1970, a number that increased more than four-fold by 1995. Some 2.5 billion people, or two-fifths of the world's population, are now at risk from dengue (WHO, 2002; Achu, 2008). A family of viruses that are transmitted by mosquitoes causes the fever (DEN-1,-2,-3,-4). It is an acute disease of abrupt onset that usually follows a benign course, with headache, fever, exhaustion, severe joint and muscle pain, swollen glands and rash (Achu, 2008). In addition, DF attacks people who have low levels of immunity; therefore, it is possible to get the disease multiple times. An attack of dengue produces immunity for a lifetime only from that particular type to which the patient was exposed (Cunha, 2007; WHO, 2002). There is no specific medicine or antibiotic to treat it: for typical dengue that is symptomatic, the treatment is purely concerned with the relief of symptoms (WHO, 2002; Cunha, 2007).

Nowadays, DF affects most Asian countries and has become a leading cause of hospitalisation and death among different ages in several of them. It is prevalent throughout the tropical and subtropical regions around the world, predominantly in urban and semi-urban areas. Outbreaks have occurred in the Caribbean, the U.S. Virgin Islands, Cuba, Central America, Australia, Saudi Arabia and other region. Cases have also been imported via tourists returning from areas with widespread dengue, including Tahiti, the South Pacific, Southeast Asia, the West Indies, India and some countries in the Middle East (Cunha, 2007; Achu, 2008). The virus is contracted from the bite of a striped *Aedes aegypti* mosquito that has previously bitten an infected person. The mosquito flourishes during rainy seasons but can breed in water-filled flowerpots, plastic bags and cans year-round.

Ecosystem changes can be used at the landscape level to control mosquito-borne disease. Spatial epidemiology is defined as the study of spatial variation in disease risk (Ostfeld et al., 2005). An integrated analysis at the landscape scale allows a better understanding of interactions between changes in ecosystem and climate, land use and human behaviour, and the ecology of vectors. Scientists such as Eugene Pavlovsky formalized theanalyses and the various changes that affect the interactions in the 20th century (Lambin et al., 2010).

These ideas can be easily implemented in a GIS environment. GIS has been applied in a number of studies of dengue fever. Barrera et al. (2000) investigated the stratification of a city with hyper-endemic dengue transmission to identify hotspots for the application of surveillance and control measures. GIS has also been applied to analyse economic resources and diseases with reference to DF and malaria in Thailand (Indaratna et al., 1998). Healthcare resources in relation to geographical distribution were examined in this study. The results showed that, at national and multi-country levels, disease data and socioeconomic data collection limit the dynamic interpolation of the two data sets in different times and ways (Indaratna et al., 1998).

Tran et al. (2004) used the Knox test, a classic space-time analysis technique, to detect spatio-temporal clustering and demonstrated the relevance and potential of the use of GIS and spatial statistics for elaboration of a dengue fever surveillance strategy. Using frequency, duration and intensity indicators, Wen et al. (2006) developed a model of spatial health risk with temporal characteristics to map the distribution of dengue cases and identify risk areas. Some studies have been in relation to the vector of dengue. Strickman and Kittayapong (2002) identified locations with higher concentrations of the vector using spatial analysis. To visualise and map the effect of open marsh water management (OMWM) for mosquito vector control when merged with invasive plant and salt marsh restoration, GIS was used. The result presented a significant reduction in the frequency of finding larvae on the marsh surface, leading to the loss of spatial larval hotspots in the area under OMWM (Rochlin et al., 2009).

Morrison et al. (1998) investigated a space-time analysis of reported dengue cases during an outbreak in Florida in 1991–1992. Pratt (2003) did research using Down-to-Earth Approach Jumpstarts GIS for Dengue Outbreak, and he found that "Incorporating traditional epidemiological statistical techniques into a GIS interface allowed researchers to gain a greater insight into the spatial aspect of the spread of the disease". Tan and Song (2000), in their study of the use of GIS in ovitrap monitoring for dengue control in Singapore, developed three models to monitor, analyse and evaluate ovitrap breeding data to better understand the *Aedes* situation on the island for planning vector surveillance and control operations. Household surveys of dengue infection during 2001–2002, spatial point pattern analysis and risk factor assessment were used to illustrate the spatial heterogeneity in the dengue risk areas when using the spatial approach in short time intervals. The result showed that the low prevalence areas in 2001 shifted to high-risk areas in the following year (Siqueira Junior et al., 2008).

Schafer and Lundstrom (2009) used the geographical distribution of *Aedes sticticus* and climate change data to model the future distribution of this vector. The model showed that potential *Aedes sticticus* areas with suitable conditions will likely increase. An information value method in the GIS environment was used to analyse and obtain the influence of physio-environmental factors such as land use and land cover on the incidence of DF (Nakhapakorn & Tripathi, 2005). Chansang and Kittayapong (2007) integrated the immature sampling methodology with GIS technology to produce spatial density distribution maps and to identify clusters of immature stages and breeding sources for improving the surveillance and control systems of *Aedes aegypti*. This study found that water jars of various types and cement bath basins were the two main breeding sources. In the state of Hawaii, geographic analysis and GIS spatial/temporal analysis were conducted on 2001–2002 DF outbreaks to create dengue threat model (DTM) (Napier, 2001). Takumi et al. (2009) assessed whether *Aedes albopictus* that were found at Lucky Bamboo import companies in the Netherlands could establish in order to produce subsequent generations. Based on GIS and collected climatic variables data, they located the suitable and unsuitable regions for the *Aedes albopictus* species.

In Rio de Janeiro State, Brazil, maps of *Aedes aegypti* density were generated using the infestation index obtained from the *Aedes aegypti* Infestation Index Rapid Survey. The map presented five areas with high and medium density of positive *Aedes aegypti* breeding locations and highlighted small block clusters with high larvae density (Lagrotta et al., 2008). Chaikoolvatana et al. (2007) aimed to develop a GIS for *Aedes aegypti* surveillance and DHF in northeastern Thailand. The development went through three stages: collecting primary and secondary data such as dengue vector incidence, water storage containers and the number of reported DHF cases/100,000 population; analysing the data; searching the target location; and presenting the results via figures on maps. There was an increase in the number of dengue cases during the high disease incidence, suggesting a strong correlation between peak rainfall, the high density of *Aedes aegypti* mosquitoes and the high incidence of DF cases. In Singapore, the public assumed that the *Aedes aegypti* mosquito bred indoors and that people were infected in their homes, while GIS showed that the groups most infected by DF were very mobile, such as teenagers and young adults who spent most of the time outdoors. The surveillance systems were changed to fortnightly checks on outdoor areas. The result of this change showed a decline in the number of DF cases (Tan, 2001). In this study, as an example, we can observe how GIS can lead to a decision that can prevent the prevalence of the disease.

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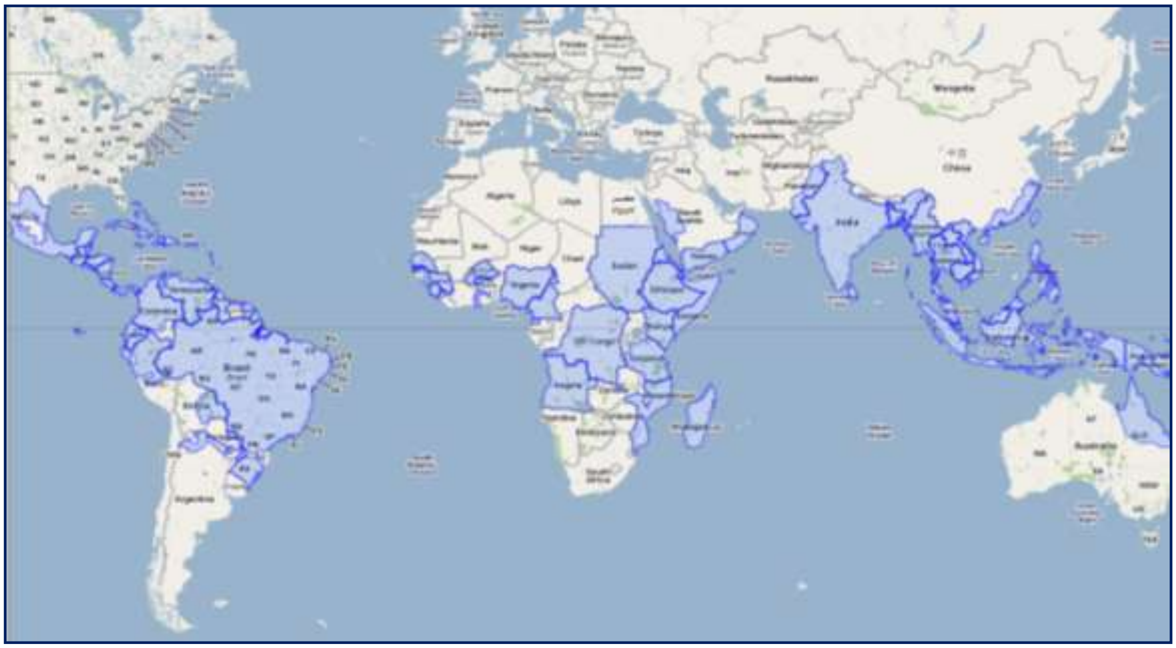

Figure 1.1: Global distribution of dengue fever. (Source: http://www.healthmap.org/dengue/index.php)

1.2 Problem Statement

In Saudi Arabia, DF is an increasing public health issue (Ministry of Health, 2011), and in Jeddah alone more than 8,000 people were affected by dengue fever from 2006 to 2010 (Jeddah Health Affairs, 2011). This number reflects the dangerous situation of disease spread. Therefore, DF has become a serious problem to many national agencies in the country. Finding the causes of the disease prevalence has become important in order to prevent dengue fever risk and minimise its impacts.

1.3 Aim and Objectives

The main aim of this study was to develop dengue fever risk models at different spatial and temporal scales for Jeddah based on different environmental, climatic and socioeconomic variables. The objectives of the study were:

- to review the related literature of GIS and remote sensing (RS)applications on mosquito-borne diseases worldwide, including DF infection in Jeddah, Saudi Arabia;
- to identify and visualise the hotspots and cold spots, and to analyse the spatial pattern of DF cases and vectors (*Aedes aegypti*) from 2006 to 2010 in Jeddah, Saudi Arabia;
- to describe and analyse the relationship between the climatic variables and *Aedes aegypti*;
- to develop regression models for predicting weekly *Aedes aegypti* abundance;
- to verify the quality of neighbourhoods in each district using high spatial resolution satellite images and to use these to model dengue risk;
- to illustrate the effect of socioeconomic factors on dengue fever incidence;
- to model spatio-temporal risk changes in dengue fever incidence;
- to assess dengue fever risk based on socioeconomic and environmental variables in a GIS environment;
- to illustrate the importance of appropriate temporal and spatial scales for dengue fever control and management; and
- to identify the weaknesses in current DF control practices and suggest improvements.

1.4 Significance of This Study

This study is important because it describes the prevalence of dengue fever and *Aedes aegypti* using geographical techniques such as geographic information systems and remote sensing, and geo-statistics methods in relation to environmental, socioeconomic and climatic factors. It adds positively to the areas of health, GIS and remote sensing. Based on the known research, this study is the first that identifies, determines and analyses the trends, movement and distribution of mosquitoes and DF in Saudi Arabia. Also, based on the known research, it is the first to describe the relationships between environmental, climatic and socioeconomic factors and DF cases and vector, to model the suitable areas for breeding and to find areas of human risk in Jeddah depending on different factors and temporal risk indices. To date, this study is the first to describe this association on the basis of five years of weekly data in Jeddah. For Saudi Arabia, to date, there have been no published studies using GIS and its spatial statistical methods to model and analyse the spatial relationship between dengue fever cases, population, population density and neighbourhood quality, or to create a predictive model of levels of risk based on this relationship and descriptively analyse the prevalence of dengue fever based on the nationality and age group of infected individuals. Based on the known research worldwide, this study is the first to use high-resolution satellite images to verify socioeconomic parameters such as neighbourhood quality and a proxy indicator for true population density, which were then used to create a predictive risk model of people likely to be infected by dengue fever. Based on the known research, this study is also the first to model areas for different monthly risk levels over a five-year period based on daily data on the occurrence of DF. To date, there have been no published studies using GIS and its spatial statistical methods to model and analyse dengue fever vector hotspots at these different scales and show their impacts on management decisions.

1.5 Content and Structure of the Thesis

The thesis starts by working through a review of literature related to GIS and RS applications in vector-borne diseases, including different dengue fever situations in different regions of the world and Saudi Arabia, to evaluate the impact of climate, human factors, environmental factors and mosquito characteristics on vector-borne diseases and DF **(Chapters 2 and 3).** Chapters 2 and 3 have been published in the *Journal of Food Agriculture and Environment*. Beginning with Chapter 4, eight chapters follow that show how GIS can be applied in the study of DF prevalence and spread. Each of these chapters has been published in reputable journals. There was an inevitable degree of repetitiveness in the manuscripts' introduction and methods, since each manuscript was designed to stand alone.

The aim of the first manuscript was to identify and visualise hotspots and analyse the spatial pattern of DF cases and vectors from 2006 to 2010 in Jeddah, Saudi Arabia **(Chapter 4)**; that chapter has been published in *Dengue Bulletin*. The second manuscript described and analysed the association between meteorological variables and *Aedes aegypti* **(Chapter 5)**; that chapter has been published in the *Journal of Food Agriculture and Environment.* The third manuscript reports the development regression models for predicting *Aedes aegypti* abundance on a weekly basis **(Chapter 6)**; that chapter has been submitted to *Global Health Perspective*.

The aim of the fourth manuscript was to verify the quality of neighbourhoods in each district using SPOT satellite images (2.5 m spatial resolution) to study the effect of socioeconomic factors on dengue fever incidence and to model dengue fever risk based on socioeconomic parameters, nationality and age groups **(Chapter 7).** That chapter has been published in *Science of the Total Environment.*

The fifth manuscript demonstrates and models spatio-temporal risk changes in dengue fever incidence **(Chapter 8).** The sixth manuscript assesses dengue fever risk based on socioeconomic and environmental variables in a GIS environment **(Chapter 9).** These two chapters have been published in *Geospatial Health*.

The seventh manuscript illustrates the importance of appropriate temporal and spatial scales for dengue fever control and management **(Chapter 10)**; that chapter has been published in *Science of the Total Environment*. The last manuscript reports the weaknesses in current DF control practices and how to improve them from a GIS prospective. Also, it includes the conclusion and summary of the study findings and provides some recommendations **(Chapter 11)**. Part of that chapter has been published in *Dengue Bulletin*.

CHAPTER 2: EXAMPLES OF USING SPATIAL INFORMATION TECHNOLOGIES FOR MAPPING AND MODELLING MOSQUITO-BORNE DISEASES BASED ON ENVIRONMENTAL, CLIMATIC, SOCIO-ECONOMIC FACTORS AND DIFFERENT SPATIAL STATISTICS, TEMPORAL RISK INDICES AND SPATIAL ANALYSIS: A REVIEW

This chapter has been published as:

Khormi, M. H. & Kumar, L. (2011). Examples of using spatial information technologies for mapping and modelling mosquito-borne diseases based on environmental, climatic, socio-economic factors and different spatial statistics, temporal risk indices and spatial analysis: A review. *Journal of Food, Agriculture and Environment* **9**(2):41-49.

CHAPTER 3: USING GEOGRAPHIC INFORMATION SYSTEM AND REMOTE SENSING TO STUDY COMMON MOSQUITO-BORNE DISEASES IN SAUDI ARABIA: A REVIEW

This chapter has been published as:

Khormi, H. M., & Kumar, L. (In Press). Using geographic information system and remote sensing to study common mosquito-borne diseases in Saudi Arabia: A Review. *Journal of Food, Agriculture and Environment. Vol 11(1).*

CHAPTER 4: IDENTIFYING AND VISUALISING SPATIAL PATTERNS AND HOTSPOTS OF DENGUE FEVER CLINICALLY-CONFIRMED CASES AND FEMALE *AEDES AEGYPTI* MOSQUITOES IN JEDDAH, SAUDI ARABIA

This chapter has been published as:

Khormi HM, & Kumar L. (2011) Identifying and visualising spatial patterns and hotspots of dengue fever: clinically-confirmed cases and female *Aedes aegypti* mosquitoes in Jeddah, Saudi Arabia. *Dengue Bulletin*. 35: 15-34.

CHAPTER 5: DESCRIBING AND ANALYSING THE ASSOCIATION BETWEEN METEOROLOGICAL VARIABLES AND ADULT *AEDES AEGYPTI* MOSQUITOES

This chapter has been published as:

Khormi HM, Kumar L, & Elzahrany R. (2011). Describing and analysing the association between meteorological variables and adult *Aedes aegypti* mosquitoes. *Journal of Food, Agriculture and Environment*. 9: 954-959.

CHAPTER 6: REGRESSION MODEL FOR PREDICTING WEEKLY ADULT FEMALE *AEDES AEGYPTI* BASED ON METEOROLOGICAL VARIABLES: A CASE STUDY OF JEDDAH, SAUDI ARABIA

This chapter is published as:

Khormi, H. M., Kumar, L., & Elzahrany, R. (Under reveiw). Regression model for predicting weekly adult female *Aedes aegypti* based on meteorological variables: A case study of Jeddah, Saudi Arabia. *Global Health Perspectives.*

CHAPTER 7: MODELING DENGUE FEVER RISK BASED ON SOCIOECONOMIC PARAMETERS, NATIONALITY AND AGE GROUPS: GIS AND REMOTE SENSING BASED CASE STUDY

This chapter has been published as:

Khormi HM, & Kumar L, (2011). Modelling dengue fever risk based on socioeconomic parameters, nationality and age groups: GIS and remote sensing based case study. *Science of the Total Environment*, 409**,** 4713-4719.

CHAPTER 8: MODELING SPATIO-TEMPORAL RISK CHANGES IN THE INCIDENCE OF DENGUE FEVER IN SAUDI ARABIA: A GEOGRAPHICAL INFORMATION SYSTEM CASE STUDY

This chapter has been published as:

Khormi HM, Kumar L, & Elzahrany R. (2011). Modeling spatio-temporal risk changes in the incidence of dengue fever in Saudi Arabia: a geographical information system case study. *Geospatial Health*. 6:77-84.

CHAPTER 9: ASSESSING RISK OF DENGUE FEVER BASED ON SOCIOECONOMIC AND ENVIRONMENTAL VARIABLES IN A GIS ENVIRONMENT

This chapter has been published as:

Khormi, H.M, & Kumar, L. (2012). Assessing dengue fever risk based on socioeconomic and environmental variables in a GIS environment. *Geospatial Health*. 6(2): 171-176.

CHAPTER 10: THE IMPORTANCE OF APPROPRIATE TEMPORAL AND SPATIAL SCALES FOR DENGUE FEVER CONTROL AND MANAGEMENT

This chapter has been published as:

Khormi, H.M, & Kumar L. (2012). The importance of appropriate temporal and spatial scales for dengue fever control and management. *Science of the Total Environment.* 430: 144–149.

CHAPTER 11: CONCLUSION

Part of this chapter has been published as

Khormi, H. M., Kumar, L., & Elzahrany, R. (2012). The benefits and challenges of scaling up dengue surveillance in Saudi Arabia from a GIS perspective. *Dengue Bulletin,* 36.

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