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Spatial changes in the distribution of malaria vectors during the past 5 decades in Iran

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ABSTRACT

Background: Global warming and climate change affect various aspects of mankind, including public health. *Anopheles* mosquitoes are of Public Health importance and can be affected by global warming and other environmental variables. Here, we studied the distribution of *Anopheles* vectors of malaria in relation to environmental variables in Iran.

Methods: Long-term meteorological and entomological data of about 50 years in retrospect were collected and arranged in a geo-database and analyzed using ArcGIS ver. 9.3 and exported to SPSS ver. 20 for statistical analysis.

Results: Distribution maps have been updated for seven species of *Anopheles vectors of malaria* which involved *Anopheles culicifacies s.l., An. fluviatilis s.l., An. stephensi, An. dthali, An. sacharovi, An. maculipennis.l. and An. superpictus* in Iran. Distribution maps of vectors were made based on district areas using Kriging model. Historical and recent records were demonstrated for each *Anopheles* based on climatic factors in the distribution areas of each *Anopheles* vectors.

Discussion: Iran, like other parts of the world is faced with warming and this probably affected the distribution of *Anopheles* vectors. Despite the warming phenomenon, the country's climate had changed during the cold season as temperatures became *colder* or cooler. This study shows that some vectors had migrated from the central part of Iran with dry and sunny landscape, moved towards the mountainous areas of the north or the warm and humid areas of the south. Historical records show that these anophelines have previously been distributed in lowland areas. If this process continues in the future, *Anopheles* mosquitoes may be seen in low lands with cold areas in central and northern parts of the country or will occupy humid and warm climates in the southern parts of the country where water is more available.

1. Introduction

Global warming is an important modern phenomenon which may affect many aspects of human civilization including public health and communicable diseases among humans. However, some unfavorable weather conditions may affect thousands of people every year (Abrahams et al., 2012; WHO, 2012). One of the most damaging effects of global warming is the occurrence of extreme events and changes in the intensity and frequency of their formation (Dalaei et al., 2014). Although the events are limited and rarely happen, they still have direct effect on vulnerable countries and regions (Farajzadeh-asl, 2013). The climate occurrence depends on extreme conditions of temperature and precipitation. Therefore, this necessitates the considerations for substantial data on extreme climate (Taghavi and Mohammadi, 2005).

Located in the Middle East and lying within longitudes 44° to 63.5° East and latitudes 25° to 39° North, Iran encompasses a land mass of 1648195 km^2 area with a population of about 78 million. The country contains mountainous areas with a semi-dry landscape. More than half of this area consists of mountains; a plain and desert quarter and less than one quarter constituting agricultural lands. The altitude ranges from the highest Damavand of

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Table 1
Climate zones of Iran and their main criteria.

Climate Code	Name of the zone	Main criteria	Factor Power					
			Temperature	Humidity and cloud	Rain	Winds and Dust	Sun-Radiation	Thunder
1	Southern boundary zone	Hot/Sun-Radiation/Humid	2.12	1.72	−0.68	0.26	1.96	−57
2	Caspian hinterland area	Rainy/Humid	0.46	2.06	2.33	−1.11	−1.84	−0.95
3	Central Iran area	Sun-Radiation/Hot	−0.24	−0.46	−0.52	−0.42	−0.22	−0.57
4	Azeri area	Humid/Thunder	−0.84	0.93	−0.35	0.00	−0.20	0.77
5	Khuzi area	Hot/Rainy/Thunder/Wind-Dust	1.63	−0.38	0.52	0.45	−1.39	0.49
6	Moghani area	Humid/Wind	−1.43	2.90	−0.98	0.81	−0.35	−0.46
7	Western Zagros region	Rainy/Thunder	0.14	−0.56	1.69	−0.40	0.00	0.84
8	Eastern Zagros region	Rainy/Wind/Radiation	−1.48	0.20	1.11	0.80	0.79	−0.24
9	Caspian littoral area	Rainy/Humid	0.97	2.20	5.64	−0.86	−2.73	−2.83
10	South hinterland area	Hot/Sun-Radiation/Wind-Dust	1.35	0.05	0.00	0.20	0.90	0.12
11	Large Sistani area	Wind-Dust	−0.19	−0.52	−0.28	2.46	−0.96	−0.48
12	Baluchi area	Thunder	0.68	−1.47	−0.30	0.91	−0.26	2.13
13	Makoui area	Thunder/Humid	−1.13	1.26	−0.64	−1.16	0.00	3.54
14	Small Sistani area	Strong Wind-Dust	0.18	−0.19	−0.49	5.69	−0.67	−0.36
15	High Zagros area	Rain/Radiation	−1.44	−1.02	4.00	0.32	2.38	0.64

5628 m in the central Alborz Mountains to 56 m above sea level in the Lut Desert. Generally divided into four major categories, the climate of Iran includes the Northern temporal climate in the Caspian Sea's littoral area, the southern hot and humid climate in the Persian Gulf, the littoral area of Oman Sea, the colder mountainous climate in the northern and western Iran, and the hot and arid climate in the central and southeastern Iran. These major climates are further divided into15 smaller climatic area based on "Sunlight", "Temperature", "Cloud and Humidity", "Precipitation", "Wind and Dust" and "Thunders", which include Azari, Central, Moghani, Makui, Khuzi, Baluchi, Major Sistani, Minor Sistani, North (East) Zagros, South (West) Zagros, High Altitude Zagros, Southern littoral, Southern Post-littoral, Northern littoral and Northern Post-littoral (Massoudian, 2001; Salahi-Moghaddam et al., 2011), (Table 1).

Malaria remains an important parasitic disease with global impact and distribution. About 3.4 billion people reside in malaria endemic areas. In 2014, malaria was reported from 97 countries and territories around the world (WHO, 2013). Caused by the protozoa of the genus, *Plasmodium*, malaria is through the bites of infected female *Anopheles* mosquito vector (WHO, 2010). Different factors including the parasite, vector, the human host and the environment are involved in intensifying its transmission. The spatial limits of its distribution and seasonal activity are sensitive to climatic factors, as well as the local capacity to control the disease. This disease is still considered as an important health problem in Iran, though almost in the elimination phase. About 31 different *Anopheles* species have been found in the country, of which eight of them include *Anopheles culicifacies s.l., An. fluviatilis s.l., An. stephensi, An. dthali, An. sacharovi, An. maculipennis s.l., An. superpictus s.l.* and *An. pulcherrimus* are regarded as the main or probable vectors of malaria (Salahi-Moghadam et al., 2014; Sedaghat and Harbach, 2005; Sedaghat et al., 2003a, 2003b). Some anophelines are only found in a restricted geographic range, while others have much wider distribution in the country. Their activities, including host-seeking and blood-feeding behaviors, are associated with a set of environmental conditions such as temperature and humidity. The transmission of malaria is also attributed to climatic conditions that may affect the density and longevity of the mosquitoes. Recently, the shifting distributions of malaria vectors and also malaria transmission have been investigated in different parts of the world (Houghton et al., 2001; Siraj et al., 2014). It seems these phenomena are due to land use alteration, changes to vector control measures, insecticide resistance, anti-malarial drug resistance, and more importantly, climate change (Siraj et al., 2014; Walther et al., 2002). The resurgence of anopheline vectors in highland regions have been reported from some countries (Siraj et al., 2014).

A study conducted in China suggested that the environmentally suitable area for *An. dirus* and *An. minimus* would increase under three climate change scenarios for the 2030 s, but will decrease in the 2050s. However, the distribution of two other vectors, i.e. *An. lesteri* and *An. sinensis* would be increased. This means the population at risk of transmission will be altered, hence the prevention and control planning strategies should be changed accordingly (Ren et al., 2016). This present study investigated long-term meteorological trends in relation to the distribution of *Anopheles* vectors in Iran in the past five decades. Distribution maps were provided using Geographic Information System (GIS) for seven main Malaria vectors in Iran. In a clearer understanding of the population movement of *Anopheles* species in past decades and probable effect of climate change on their ecological niches, this study was eventually conducted in 2015.

2. Method

2.1. Study area and climatology

According to the eco-zones or Zoogeographical regions, Iran is located in the Palearctic zone, but South and south-eastern parts of the country are highly influenced with climatic conditions of Afrotropical and Indo-Malayan.

Climatological studies of Iran shows that the Northern, Western and South-Western regions, totaling an area of 31 percent, constitute 52 percent of precipitation and 69 percent of runoff; while 69 percent of the landmass of the country produce 44% of precipitation and 31% of runoff. In relation to the climate change prediction in Iran, precipitation would decrease in northwest, west and southwestern parts of the country, and would increase across the East, southeast and central regions. Another prediction estimated that the average temperature would increase by nearly 1.4 °C by the year 2039. Climate data shows that the intensity of rainfall for the cold season in these areas has been increased in recent years (Dalaei et al., 2014).

2.2. Data and method

Climate data were provided for a period from 1981 to 2010 from meteorological and climatological networks. Daily synoptic stations data were extracted from 52 stations in Iran since 1981 (Tables 2 and 3). The data were used from selected meteorolog-