INTRODUCTION

Environmental changes give rise to numerous opportunities for unexpected or enhanced risks from vector-borne diseases. The best method to interrupt any vector-borne disease is to reduce human vector contact **(Sharma and Singh, 2008).** Vector control is the key intervention for the elimination of vector borne diseases. Currently, using indoor insecticide residual spraying (IRS) and impregnated bed nets are the main strategy recommended in vector control and widely used especially in mosquitoes and sand flies vectors **(WHO, 1995 & 2000).** Indoor residual spraying is the application of a long lasting, residual insecticide to potential vector resting surfaces such as internal walls, roof space, and ceilings of houses or structures (including domestic animal shelters). The effectiveness of IRS arises from the fact that many important vectors are endophilic. When vectors come into contact with a sprayed surface, it absorbs lethal doses of insecticide, thereby reducing its lifespan **(WHO, 2013).**

Indoor residual spraying of DDT and its alternatives was introduced in many countries in the 1940s to control mosquito vectors, but because their environmental hazards and wide spread resistance, synthetic pyrethroids have been developed to replace such insecticides **(WHO, 1995 and Najera & Zaim, 2002).** Pyrethroids are more or less environmental safe due to photo-degradability and low toxicity **(Jana Kara *et al.*, 1995).** The efficacy of indoor residual spraying (IRS) depends, among other things, on the proportion of vectors resting on the sprayed surface and on the susceptibility of the vectors to the insecticide used. It is therefore important to monitor the development and extent of insecticide resistance in a given vector population **(WHO, 2006).** The emergence of resistance of several vectors to insecticides threatens successful vector control in some countries **(Chaccour *et al.*, 2013).** New tools were suggested for reducing malaria transmission, but nevertheless, chemical insecticides are still essential, and in most malaria-endemic countries, especially sub-Saharan Africa, IRS remains an important method of fighting endophilic malaria vectors **(Padonou *et al.,* 2012).**

The persistence of an insecticide sprayed on a surface varies with the type of insecticide, its formulation and the type of surface **(Ansari *et al.*, 1997)**. Therefore, the determination of residual activity of insecticides is essential information for the selection of appropriate indoor spraying operation. The importance of a more precise definition of the duration of the residual effect is in the need for programming cycles so that the human population remains protected until a new spraying is conducted **(Etang, 2011).**

Phlebotomine sand flies are major biting insects of man and are the vectors of several viruses, the bacterium *Bartonella bacilliformis*, and, most importantly, the protozoan parasites that cause leishmaniasis. Worldwide, there are an estimated 2 million new cases of leishmaniasis annually, and 12 million people are currently believed to be infected with leishmaniasis **(WHO, 2008).** Throughout North Africa, the Middle East and Southwest Asia, *Phlebotomus papatasi* is the primary vector of *Leishmania major*, the causative agent of zoonotic cutaneous leishmaniasis (ZCL). Fauna of Egypt is represented by 21 species of sand flies; the dominant species is *Phlebotomus papatasi*.

Mosquitoes are among the most serious insect pests of medical importance. *Culex pipiens*, the common and widely distributed mosquito across Egypt, has been incriminated as the main vector of bancroftian filariasis **(Southgate, 1979)** and the Rift Valley fever (RVF) **(Meegan *et al.*, 1980).** *Culex pipiens* has been implicated also as a major vector of West Nile Virus **(Andreadis, 2012).**

Accordingly, this study was designed to primarily evaluate insecticide effectiveness against *Phlebotomus papatasi* and *Culex pipiens* applied to different wall surfaces. In addition, the persistence of the insecticides applied on different wall surfaces was investigated.

LITERATURE REVIEW

1. Arthropod vectors

1.1. Sand flies

Sand flies belong to the family Psychodidae, which is among the most primitive families of Diptera. Some general characteristics that can be used to distinguish sand flies from other small flies include their size (1.5 to 2.5 mm in length), characteristic hopping flight, and the "V" position in which they hold their wings while resting. Sand flies are divided according to Genera to Old World and New World sand flies. There are two Old World genera within the subfamily Phlebotominae: *Sergentomyia* and *Phlebotomus* **(Lewis, 1982)**. Sand flies in the genus *Sergentomyia* feed primarily on lizards, and may be the vectors of the agents of saurian leishmaniasis. Sand flies of the genus *Phlebotomus* feed on mammals, and represent all of the medically important sand flies in the Old World. There are three New World genera within subfamily Phlebotominae: *Brumptomyia, Warileya,* and *Lutzomyia* **(Young and Duncan, 1994).**

Sand flies are found in a wide variety of habitats, ranging from desert to rainforest. They occur mostly in the tropics and subtropics. Although sand flies are principally found in the warm parts of the world including southern Europe, Asia, Africa, Australia and central and south America, their distribution extends to temperate regions above latitude 50ºN in south west Canada **(Young and Perkins, 1984)**. The areas with characteristic *Phlebotomus* resting and breeding sites are rather cool, dark and humid including houses, cellars, caves, dray walls with cracks, soil rich in organic material, presence of poultry and domesticated animals, animal shelters providing shaded resting sites for adults, dense vegetation; tree holes; burrows of rodents; bird's nests; and termitaria **(Maroli and Guandalini, 1985, Killick-Kendrick, 1999).**

Like all Diptera sand flies have four stages in their life cycle: egg, four larval instars, pupa and adult. Most or all species feed on natural source of sugar such as plant juice **(Muller and Schlein, 2004).** Females feed on blood which provides nutrition for the production of eggs. Some species are able to produce the first batch of eggs without a blood meal (autogeny) **(El Kammah, 1973, Kassem and Hassan, 2003).** Females of most species take blood meals only once per gonotrophic cycle. The number of eggs laid by a single female at one time varies greatly among species and depends on some factors such as species of blood meal host or ambient temperature, but frequently, it diverges between 40 to 70 eggs **(Young and Duncan, 1994).**

Sand flies of more than 30 species in the genus *Lutzomyia* and 40 species in the genus *Phlebotomus* are vectors of human pathogens. Phlebotomine sand flies are the vectors of several diseases such as viruses **(Turell and Perkins, 1990),** the bacterium *Bartonella bacilliformis* **(Young and Duncan, 1994),** and most importantly, nearly 20 species of protozoan parasites in the genus *Leishmania*. Sand fly fauna of Egypt composed mainly of 21 sand fly species, eight of the genus *Phlebotomus* and 13 of the genus *Sergentomyia* **(Lane, 1986).**

Kamal *et al.* 2003, investigated the human zoonotic cutaneous leishmaniasis and associated sand flies in Sheikh Atiya village, southern Sinai, Egypt. A total of 784 phlebotomine sand flies were collected. Sand fly species composition at Sheikh Atiya village showed that *Phlebotomus papatasi* and *P. alexandri* were the most abundant species in the area and each comprises about 47 % of the flies collected. *Phlebotomus sergenti* and *P. kazeruni* occurred in very low numbers.

Kassem *et al.* 2009, carried out an ecological study on sand flies in two villages in Nile Delta, Egypt. A total of 9529 sand flies were collected during this study, all of which were identified as *P. papatasi*. This study revealed that sand fly activity started from April to December with a bimodal annual pattern and its activity was highly positively correlated to fraction illumination.

Darwish *et al.* 2011, studied the vectorial competence of *P. papatasi* to transmit two old world *Leishmania* species in Egypt. The *P. papatasi* used in this study were originally collected from Suez Governorate in Egypt. This study revealed that *P. papatasi* vectored *Leishmania major* but failed to transmit *Leishmania tropica*.

Hoel *et al.* 2011, studied the use of different carbon dioxide sources in sand fly surveillance programs in north Aswan, Egypt. During that study, 1,842 phlebotomine sand flies were collected. *Phlebotomus papatasi* formed more than 90% of the total catch, while *P. sergenti*, *S. schwetzi*, *S. palestinensis*, and *S. tiberiadis* formed the rest.

Hogsette *et al.* 2008, conducted a survey to identify the diurnal resting sites of adult phlebotomine sand flies in a village in southern Egypt. Sand flies were aspirated from piles of mud bricks using the backpack aspirator. Fifteen sand flies, consisting of 12 *P. papatasi* and three *S. schwetzi* were collected. They find that mud bricks are being used as diurnal resting sites by large numbers of sand flies. They propose to find and characterize diurnal resting sites of sand flies in a structured environment inhabited by humans along with domestic and feral animals. Results can lead to discovery of diurnal resting sites in less structured habitats and ultimately lead to more effective adult sand fly control.

Kassem *et al.* 2012, studied the environmental factors underlying spatial patterns of sand flies in southern Sinai, Egypt. This study reported that *P. alexandri*, *P. kazeruni* and *P. sergenti* were widespread and abundant, *P. papatasi* and *P. bergeroti* were less frequent, and *P.*

arabicus, *P. major* and *P. orientalis* had highly restricted distributions. The logistic regression models indicated that elevation and climatic conditions were limiting determinants for the distributions of sand flies in southern Sinai. The spatial parameters studied in this research indicated that quarter of the surface area of Sinai peninsula forms a potential habitat for *P. papatasi*, the main vector of leishmaniasis in Egypt.

Samy *et al.* 2014, analyzed the data collected over seven years (January 2005-December 2011) in North Sinai, Egypt to track CL transmission with respect to both sand fly vectors and animal reservoirs. The study identified six sand fly species collected from different districts: *Phlebotomus papatasi*, *P. kazeruni*, *P. sergenti*, *P. alexandri*, *S. antennata* and *S. clydei*. Only *Leishmania major* was isolated and identified in 100% of the parasite samples.

1.2. Mosquitoes

Mosquitoes are relatively fragile insects with an adult life span that lasts about two weeks. The subfamily Culicinae contains 34 genera of mosquitoes, of which only 4 genera are collected from Egypt; *Culex, Culiseta, Uranoteniae* and *Ochlerotatus.* The genus *Culex* is found in both temperate and tropical regions. These mosquitoes tend to hibernate over the winter and breed during the warmer months.

All mosquitoes go through the same life cycle: egg, four larval stages, pupal stage, and adult (complete metamorphosis). The duration of each stage depends on the temperature. In general, it takes ten days for mosquitoes to develop from egg to adult. The egg stage lasts about two days, and then goes through four larval stages in 6-7 days followed by the pupal stage lasting one or two days. The male mosquitoes mate with two or three females, only feeds on plant juices (males cannot bite or take blood meals due to absent of penetrating mouth parts), then die after just a few days. The female mate only once in her life and store the sperm in a special sac to fertilize every batch of eggs. After mating, the female seek for a source of blood to produce eggs, feeding on a man or animal, and sometimes two or more, until fully engorged. Females rest for two or three days as the eggs develop. After that, the female search for oviposition site to lay eggs. After egg laying, females seek another blood meal, engorge, rest for two days, oviposit eggs again. Generally, a female mosquito lives for one or two weeks. The entire adult stage is spent undergoing this feed-engorge-oviposit cycle up to seven or more times. Each bite is an opportunity to become infected or to infect a victim. They normally don't travel more than a few hundred yards from where they hatched.

Culex spp. mosquitoes are widespread and can be found in tropical and temperate climate zones on all continents except Antarctica **(Vinogradova, 2000)**. In Egypt, *Culex pipiens* is the main vector of bancroftian filariasis **(Southgate, 1979)**, Rift Valley Fever **(Turell, 1996; Gad *et al.*, 1999)**, and incriminated vector of arbovirusis e.g. West Nile virus **(Taylor *et al.*, 1956)**. Also *Culex pipiens* is the common house mosquito inhibited almost all the different districts of Egypt.

Bahgat 2000, determined the host selection patterns of *Culex pipiens* over the mosquito's seasonal activity period (May to November) during the year 1999 at El-Abtal village, Ismailia Governorate. Results showed that almost half of the indoor tested mosquitoes had a human blood (50.7%). The outdoor collected samples had fed predominately on mammals other than humans (65.8%)**.** *Cx. pipiens* appeared to be fairly endophagic as most of the engorged females were collected from indoors and less partially from outdoors.

Mostafa *et al.* 2002, studied mosquito identification, distribution and densities in fourteen Governorates in Egypt. The study period was during 1999-2000-2001. Results showed that the *Culex pipiens*, *Cx. antennatus* and *Cx. univittatus* were the most common species. *Ochlerotatus caspius* (formally known as *Aedes caspius*) was found in Assiut and Aswan and as larvae in Kena and

El Wadi-El Gaded. *An. pharoensis* was found in Behaira and Fayium, while *An. algeriensis* in Aswan.

Hassan and Onsi 2004, conducted a mosquito larval surveys to characterize positive breeding habitats and incorporate the biological results in a GIS system. The reported mosquito species in this study were *An. multicolor*, *Cx. antennatus* and *Cx. theileri* and were found breeding in water-flooded habitats with dense vegetation cover spatially associated to existing lakes.

El-Bashier *et al.* 2006, conducted adult mosquito surveillance in Sharkia Governorate. Mosquito prevalence was significantly higher in the rural areas than urban ones. Results showed that mosquitoes were common all the year round except in January, February and March, with peaks in summer and autumn and lesser numbers in spring and winter. Also, the results indicated that urbanization and meteorological factors affects mosquito composition.

Abdel-Hamid *et al.* 2009, studied and surveyed the Culicine mosquitoes in El Sharqiya Governorate, Egypt. Totally six species were reported; *Cx. pipiens*, *Cx. perexiguus*, *Cx. antennatus*, *Cx. pusillus*, *Cx. sinaiticus* and *Ochlerotatus detritus*, respectively. The most common species were *Cx. pipiens*, *Cx. perexiguus*, and *Cx. antennatus*. It was also found that larval density of *Cx. pipiens* increased while the densities of *Cx. antennatus* and *Cx. perexiguus* decreased.

Abdel-Hamid *et al.* 2011a, conducted mosquito surveillance in El Ismailia Governorate. Nine species were reported; *Cx. pipiens*, *Cx. perexiguus*, *Cx. antennatus*, *An. tenebrosus*, *An. pharoensis*, *An. multicolor*, *Ochlerotatus detritus* (formerly known as: *Aedes detritus*), *Oc. caspius* and *Culiseta longiareolata*. The encountered dominant species were *Cx. pipiens*, *Cx. perexiguus*, and *Cx. antennatus* respectively.

Abdel-Hamid *et al.* 2011b, conducted mosquito surveillance in El Menoufia Governorate. Six species were reported: *Cx. pipiens*, *Cx. perexiguus*, *Cx. antennatus*, *Oc. caspius*, *Oc. detritus* and *Culisetalongiareolata*. *Culex pipiens* was predominating species.

Abdel-Hamid *et al.* 2011c, conducted a mosquito surveillance and ecological study in El-Gharbia Governorate, Egypt. Seven mosquito species were collected. These were *Cx. pipiens*, *Cx. perexiguus*, *Cx. antennatus*, *Cx. theileri*, *Oc. detritus*, *Culiseta longiareolata* and *An. tenebrosus*. *Culex pipiens* was the dominant species. Irrigation drains were the most productive mosquito habitat.

2. Vector control

The best method to interrupt any vector-borne disease is to reduce man-vector contact. Designing a vector control program should begin with an assessment of the risk of vector-borne diseases as well as the clinical evidence of the diseases among the displaced population.

Vector control strategies may range from simple treatments (self-protection and home improvement) to more complex measures that require participation from vector control experts (entomologists). The selection and use of different chemical and non-chemical methods for vector and pest control should be based on their efficacy, sustainability and cost-effectiveness **(WHO, 2004).**

Control strategies may be classified as environmental control, biological control, and chemical control. Chemical control has proven to be very effective to reduce vectorial capacity. Other methods like environmental management **(Rajagopatan *et al.*, 1991)** or biological control **(Reuben *et al.*, 1991)** could be applied in limited situations **(Mouchet *et al.*, 1991).** However, several methods can be combined to control vectors of disease: residual indoor sprays, impregnated bed nets, and space sprays.

2.1. Indoor residual spraying (IRS)

Indoor residual spraying is a simple and cost-effective method of controlling insects. It involves coating the walls and other surfaces of houses as well as animal dwellings and space-spraying with a residual insecticide. For several months, the insecticide will kill all susceptible insects that come in contact with these surfaces.

Currently 12 insecticides are recommended by WHO 2006 for IRS, belonging to four chemical groups (one organochlorine, six pyrethroids, three organophosphates and two carbamates). The choice of insecticide must be informed by the following considerations: insecticide susceptibility and vector behavior; safety for humans and the environment; efficacy and cost-effectiveness. Appropriate facilities must be provided for handling insecticide concentrates, both as water-dispersible powders and as emulsifiable concentrates. IRS has commonly been the intervention of choice in areas of a particular economic interest (e.g. tourism, mining, oil extraction, agricultural schemes) that requires rapid and very effective prevention, where logistic constraints do not prevail. IRS cannot be used in areas devoid of structures, such as forests or swamps **(WHO, 2006).**

2.2. Sand fly control using insecticide residual spraying

Chemical control of sand flies is still one of the most important methods of leishmaniasis prevention. However, there are some obstacles to the extensive use of these methods which include, among others, restriction on the use of insecticides, especially ones with a long residual effect, the high probability of the development of resistance to different insecticides by the sand flies, as well as difficulties of developing a method of treatment which would ensure that the insecticide will reach as far as the sand fly breeding and resting which are often inaccessible.

Davies *et al.* 2000, studied the effect of spraying inside walls and ceilings with lambdacyhalothrin on the risk for residents of cutaneous leishmaniasis (CL) in Peruvian Andes. A random selection of 112 houses were sprayed (indoor and outdoor) at 6 monthly intervals. The mortality rates of *Lutzomyia verrucarum* measured with WHO bioassay cones set on adobe walls characteristic of the endemic region. No significant drop in insecticide effectiveness over six months time period was detected either from the bioassays carried out in the field, or from the sand fly abundance data collected. However, bioassays on outdoor adobe walls indicated that lambdacyhalothrin effectiveness dropped significantly within three months of outdoor spraying. Results also demonstrated that house spraying at 6 monthly intervals can reduce the risk of CL by up to 81%.

Feliciangeli *et al.* 2003, conducted a field trial of two indoor residual sprayings with lambdacyhalothrin, the first at the beginning of November and the second at the beginning of January in El Ingenio, Miranda State, Venezuela. The residual effect of the