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Dengue and Mosquito Control Programs: A Comparative Analysis

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Authors' contributions

This work was carried out in collaboration between all authors. Authors OF, KH and AA designed the study. Author OF performed the literature searches, statistical analysis and wrote the first draft of the manuscript. Author KH completed the analysis and added content. Authors OF, KH and AA edited subsequent drafts together and finalized the manuscript.

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ABSTRACT

Aims: This paper aims to compare the effectiveness of current mosquito control programs in the control of dengue in a developed versus a developing country.
Study Design: Systematic Review and Analysis.
Place and Duration of Study: Department of Global Health, University of South Florida, Tampa, Florida, USA between August 2013 and July 2014.
Methodology: Systematic literature search of published and grey literature was done using the following databases: MEDLINE, AGRICOLA, BMC, DOAJ, Web of Science, the Cochrane Library, WHOLIS and Google Scholar. Relevant data were then extracted and analyzed.
Results: Developing countries usually start up vector control activities after an epidemic has started, resulting in a lower impact on the control and prevention of dengue. Some developing countries, despite having sustainable vector control programs, still have a high incidence of dengue. Some studies have shown that factors such as defective urban planning, low socio-economic status and poor physical housing conditions in some endemic locations within the developing countries may account for the high incidence of dengue cases. In comparison, a developed country with robust mosquito control programs that have been sustained over long period of time, with proper ongoing surveillance involving monitoring and evaluation, better

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economy, urban planning and human behavior, consistently present with low incidence of dengue infection within the past few years.

Conclusion: There are existing deficiencies in dengue vector control in developing countries such as gaps in the practice or implementation of vector control programs and existence of a sustainable mosquito control program. Further research needs to be done to determine the reasons for these gaps. Interventions need to be directed towards eliminating these gaps in dengue vector control to reduce incidence in these populations and prevent epidemics. Interventions may need to focus on policies regarding urban planning and educating the population on better practices regarding human behavior and habitation.

Disclaimer: The authors are not implying that one of the mosquito control programs being compared is superior to the other; this is simply a comparative analysis of two programs which may or may not represent standard practices of other developed and developing countries.

Keywords: Dengue; aedes; mosquito control programs; dengue epidemics.

1. INTRODUCTION

Dengue is a fast disseminating viral infection, second only to malaria in the world as an important mosquito borne disease. The incidence of dengue has been on the increase worldwide, with geographic expansion from urban to a more rural setting in the present decade. Dengue is an arthropod borne infectious disease with very complicated dynamics and has become an important issue in public health due to the increase in the incidence and spread of the disease. Dengue is transmitted by several mosquito species from the genus *Aedes*, mainly *Aedes aegypti*, which is responsible for most infections worldwide and *Aedes albopictus*, considered to be a secondary vector and is the predominant vector found in the U.S.A. spanning the South, Mississippi River Delta, and the East Coast [1]. Chikungunya is another viral borne infection found to be endemic in some parts of Africa and South East Asia and was reported for the first time in the Americas on the French part of the Caribbean Island of St Martin. Between December 2013 and March 2014, more than 17,000 suspected and confirmed cases were reported. Chikungunya even though caused by a different viral family from dengue, it has similarities in symptomatology such as fever and muscle pain and it is also transmitted by the same mosquito vectors species [2]. Various factors are responsible for the spread and transmission of dengue in urban communities such as concentration and movement of people and climatic settings for the proliferation of the vector [3]. The *Aedes* mosquitoes are usually active during the day, making control of the vector difficult; it has a high vectorial capacity (VC), which is a vector's proclivity to transmit dengue being cognizant of virus, human, vector and virus interactions [4] and a strong affinity for the blood of humans. These mosquitoes usually breed around and inside homes in containers that can hold water and they also have a limited flight range and hence they persevere in domestic environments [5]. The most important public health objective is mosquito control, as these insects may transmit several human diseases such as dengue, chikungunya, yellow fever, West Nile and Japanese encephalitis, as they cause widespread outbreaks in countries where they are prevalent [6].

There is currently no licensed vaccine available to prevent dengue transmission, but several candidates are in various phases of clinical trials. Sanofi Pasteur is developing a tetravalent dengue virus vaccine (CYD-TDV) which is currently undergoing phase II and phase III clinical studies. It is comprised of four recombinant live attenuated vaccines (CYD 1-4) and is created using the yellow fever vaccine (YFV 17D) yellow fever vaccine as a backbone. The CYD-TDV vaccine is phenotypically and genetically stable, it is not harmful to the liver, and it has less central nervous system side effects than YFV 17D. No concerns regarding safety have been raised yet and this vaccine requires a three dose regimen to induce immune response against all four serotypes. A vaccine efficacy report of 30.2% with a 95% confidence interval of -13.4% to 56.6% have been made, which is not statistically significant, making the efficacy of the vaccine to be questionable; therefore no conclusions have been drawn yet [7]. Other vaccine candidates include live-attenuated vaccines, subunit vaccines, DNA vaccines, purified inactivated vaccine candidates, tetravalent chimeric virus vaccine and additional technological approaches, such as virus-vectored and VLP-based vaccines [8]. These attempts are made towards developing a safe and effective dengue vaccine against all four serotypes of dengue virus and they are still in the experimental stages. This makes vector control the only existing approach to combating spread of dengue disease [3].

The vector control measures include biological, chemical and environmental methods and management approaches [5]. Dengue has conventionally been known to be a neglected tropical disease that is seen mainly in developing countries. However, in more recent times dengue outbreaks have been seen in developed countries with subtropical regions like the United States [1]. Since the 1950s, the Southeast Asia and western Pacific regions have had several epidemics with increase in degree of infection and are also the regions with the highest incidence of dengue [9]. These regions put together have 75% of the world dengue disease burden [5].

1.1 Overview of Global Dengue Burden

Dengue is caused by any of the four dengue flaviviruses: DENV-1, DENV-2, DENV-3 and DENV-4 which are differentiated based on their antigenic properties. Initial infection with one of the DENV serotype can cause an acute disease characterized by headache, fever, arthralgia, myalgia, retro-orbital pain, rashes and bleeding conditions like nosebleeds, bleeding gums and easy bruising. The World Health Organization recently categorized the disease as non-severe dengue and severe dengue. The non-severe dengue is further characterized as dengue without warning signs and dengue with warning signs [10]. Dengue without warning signs presents with flu-like symptoms or may be asymptomatic; dengue with warning signs presents with headache, abdominal pain, vomiting, hepatomegaly, fever, arthralgia and flushed skin. Severe dengue can present as dengue hemorrhagic fever which can be a life threatening illness following hypovolemic shock, other presentations are thrombocytopenia and plasma leakage [11].

Dengue is the most common and the most rapidly disseminating mosquito transmitted virus in the world [1]. The outbreaks of the disease constitute a heavy burden on the people, economies and health systems of the affected countries. About 3.6 billion or two-fifths of the world's population, are projected to be living in subtropical and tropical regions where the ecology and social environment allow for sustenance of dengue transmission and also where the implicated mosquito vectors are found [1]. The world-wide incidence of dengue has seen a 30-fold increase in the last half century, with a projected 50-100 million yearly new infections. However, worldwide estimations do vary and up to 200 million cases have been estimated to occur yearly, with about 500,000 cases of severe dengue and more than 20,000 deaths due to dengue occurring annually [5]. Fig. 1 shows the distribution of global dengue risk [12].

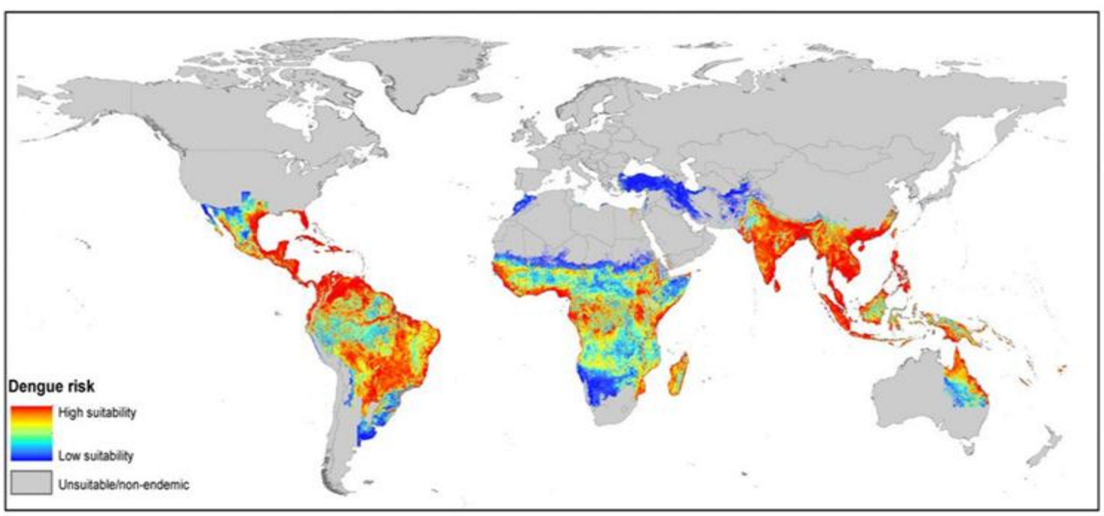

Fig. 1. Distribution of global dengue risk (WHO. (2012). global strategy for dengue prevention and control, 2012-2020. France: WHO press)

The disability-adjusted life years per million populations per year lost to dengue is 264, with a valued cost for hospitalized and ambulant cases of U.S. $514-1394. WHO, in 2012, categorized dengue as the most significant arthropod borne viral disease world-wide [12]. This is due to the substantial geographical spread of dengue and its vector to areas that were earlier not affected and also the attendant costs brought on by the disease burden [5].

The objectives of this paper are to review the effectiveness of vector control programs in one developed and another, a developing country and also to compare the current dengue endemicity status in both countries and the surrounding regions. This paper also explores the reasons for the observed differences. The United Nations Statistics Division states "the designations 'developed' and 'developing' are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process" [13]. For this paper, vector control programs in two countries are compared: The program in Malaysia, a developing country and the counterpart program in United States, a developed country.

2. MATERIALS AND METHODS

Systematic literature search of published and grey literature was done using the following databases: MEDLINE, AGRICOLA, BMC, DOAJ, Web of Science, the Cochrane Library, WHOLIS and Google Scholar. Relevant data were then extracted and analyzed.

Malaysia, a developing country and the sub-tropic regions in the United States, a developed country were the two main areas focused in for the basis of comparison for this particular study.

3. RESULTS AND DISCUSSION

3.1 Dengue in Malaysia

The World Health Organization divides the world into six WHO regions: African Region, Region of the Americas, Southeast Asia Region, European Region, Eastern Mediterranean Region and Western Pacific Region. About 75% of global dengue burden affect people living in the WHO Southeast Asia and Western Pacific regions of the world. In the Western Pacific region, about 44,353,907 dengue cases were seen in 2010 and the region continues to experience an increase. Malaysia, Cambodia, Philippines, the Lao People's Democratic Republic, Vietnam and Singapore currently have the highest burdens of dengue in the region [5]. The incidence of dengue fever was first documented in Malaysia in 1902 by Skae after an outbreak in Penang [14]. Severe dengue was first reported in 1962 and has since been on the increase [15]. During the 1980s, a shift in the peak age incidence of severe dengue from children to young adults was documented [16]. Dengue infections have continued to increase and several nationwide outbreaks were documented in the years 1974, 1978, 1982 and 1990, showing a four year cycle pattern [17]. Dengue continues to impact the livelihood, social capability and vigor of the people of Malaysia and is responsible for a 60% loss in the quality of life [16].

Trends in the cases of dengue fever and severe dengue in Malaysia show that these have been on the increase though fluctuations of increasing and decreasing trends were also observed within the last decade. The incidence rate in 1999 was 44.3 cases/100,000 population with a case fatality of 20% and increased to 187 cases/100,000 population with a case fatality rate of 0.20% in 2007 (Fig. 2) [18]. In 2011, however, the number of cases reported was 70.38 cases /100,000 with a case fatality rate of 0.18% [19]. For comparison, we summarize the reported number of cases, deaths and case fatality rates (CFR) of dengue from Australia, Viet Nam, Singapore, Philippines, Malaysia, Lao Peoples Democratic Republic and Cambodia in Table 1.

Dengue morbidity and mortality cases have been on the increase since 1990 worldwide, but new methods and tools have been put in place and used to curb the burden of dengue. Malaysia is one of the leading countries in developing and applying such new methods for controlling the vectors responsible for dengue [16].

Transmission of dengue has been linked with geographic expansion and circulation of vectors and viruses; several elements have made this expansion conducive in dengue endemic countries. The proliferation of the dengue virus is related to the increasing population, disorderly expansion or urbanization, crowding, poor sewage, waste management and water systems, the propagation of slums, an increase in tourism and commercial activities, global warming, lower resources allocated for vector control, public health policy changes and the issue of hyperendemicity among other things [20]. The Second World War, with the entry of troops and equipment led to a major increase in the circulation of the dengue vector in Southeast Asia [20].

Ae. aegypti is a well-adjusted vector breeding mosquito in both urban and domestic environments; it is seen breeding inside houses as individuals open their windows for air, as a way of life in a country like Malaysia; this creates an allowance for the vector to oviposit in plates set under flower pots and vases usually found in homes. *Ae. aegypti* breeds easily in poor communities, where the larvae are seen in water jars and water tanks, as water supply is not constant. At the same time it also breeds in upscale communities where larvae are seen in air conditioner drip containers and evaporative trays of frost free refrigerators, hence making it an equal opportunity vector. *Ae. albopictus* used to be a sylvatic/rural mosquito and is seen ovipositing in natural water holding habitations like holes in trees and in leaves of some plants. However, in recent times *Ae. albopictus* has been seen in urban areas ovipositing in containers like thrashed plastic bottles, cans, bags, tires and buckets that can hold proper amount of water after rainfall [21].

3.2 Dengue and Vector Control in the United States

For the time period of 2000-2010 there were a total number of 8,440,253 cases of dengue documented in the Pan American region; this is the highest number recorded in the region's history with 3,058 (0.036%) deaths. Severe dengue cases were 221,043 (2.6%) with a 1.38% death rate for the same time period. The total number of reported dengue cases in the North American sub region for the years 2001-2010 was 553 and no severe dengue cases were reported [22]. According to the Pan American Health Organization (PAHO) epidemiological weekly update, there has been a reported 432 cases of dengue and two cases of severe dengue and no deaths so far in the North American sub region as of November 2013 [23].

A dengue-like epidemic was documented in several cities in the United States; namely Mobile (Alabama), Savannah (Georgia), New Orleans (Louisiana), Charleston (South Carolina) and Augusta (Georgia) after 1850. New Orleans had a major dengue outbreak affecting 40,000 people in 1873, which preceded another major outbreak between 1879 and 1880 in various Southern States port cities [24]. In 1918, Galveston, Texas recorded an outbreak, and later in 1922, another outbreak with about 30,000 cases of suspected dengue was seen, which then spread to the entire states of Texas and Louisiana. Another epidemic started in Miami in 1934, which extended to the whole state of Florida and the southern parts of Georgia. More outbreaks occurred in Texas during the 1941-1946 periods and also in Puerto-Rico in 1945 [24]. The U.S. Virgin Islands had an outbreak in 2005 and also in November 2012, where 27 suspected dengue cases were reported to the CDC, of which 4 of the cases were confirmed to be dengue positive [25]. In the process of battling yellow fever, dichloro diphenyl trichloroethane (DDT) was introduced and approved by PAHO for the eradication of *Ae. Aegypti*. Additionally, prior mosquito control programs that targeted elimination of mosquito foci helped to achieve eradication of vector population in the Americas [24]. Dengue's reemergence in the Pan American region manifested in the latter part of the 1980s in several countries that had not experienced dengue in about 35 years and in the United States there have been sporadic outbreaks primarily around the United States-Mexico border. The dengue outbreak that occurred in Hawaii in 2001–2002 was comparatively small, with about 1,644 queried cases and 122 cases that were lab confirmed. This outbreak stood out because *Ae. albopictus* was the vector responsible signifying its competence in maintaining an epidemic in places where *Ae. aegypti* is absent. This was the first known autochthonous spread in Hawaii in many decade; this is noteworthy also because it emphasized susceptibility of reintroduction of dengue into a vulnerable population. In 2005 in Brownsville Texas, there were 24 cases of dengue in people with history of travel to Mexico and three autochthonous cases. Southern Florida experienced their first autochthonous case in 1946. Before the 2009-2010 dengue outbreaks in Florida, the last outbreak was in 1934, during which about 15,000 people were affected in Miami [26]. Several outbreaks have occurred in Florida in more recent times. Key West reported 29 cases in 2009 and 65 cases in 2010, all of which were locally acquired [1]. The CDC included dengue as a reportable disease in the United States following the 2009 outbreak; prior to 2009, dengue cases seen in Florida were all imported. U.S. territories, such as the American Samoa, Guam, Puerto Rico, American Virgin Islands and Northern Marianas, are zones with potential for periodic outbreaks of dengue [24]. Fig. 3 shows dengue fever and severe dengue cases in US in 2010 [27]. As of July

2014, the CDC reported 74 cases of dengue which were presented in the United States Geological Survey map, all of which are imported cases, 20 of which occurred in California. The U.S region of Puerto Rico reported 357 locally acquired cases of dengue as of July 2014 [28].

Various dynamics have been linked with this reemergence, such as urbanization which caused an increase in human population and suitable breeding conditions for the vectors. Many mosquito control programs had to continue and operate with decreased budget thus affecting operational effectiveness, the use of DDT was no longer allowed and approaches like space spraying, which are not as effective, became predominant. Furthermore, increased travel and globalization have been linked to the movement of dengue serotypes and introduction of the serotypes in susceptible environments [1].

Most of the reported cases in the United States are imported or travel-associated infections; there are about 100 imported cases into the United States annually and cases of autochthonous transmission have also been documented [29]. *Ae. aegypti* is seen mainly in the southern states of the United States. *Ae. albopictus*, since it was introduced in the middle 1980s has spread throughout the southeastern state and was responsible for the 2001 dengue outbreak in Hawaii [30]. *Ae. albopictus* was first discovered in Harris County, Texas in 1985 and was said to have been introduced by accidental transportation of the eggs in tires imported from Asia and it was introduced into California through cargo from the South Pacific between 1946 and 2004. In 2001, *Ae. albopictus* was imported from China through the shipments of Dracaena species bamboo trees that were packed in still water and this led to a severe invasion [29].

3.3 Mosquito Control Programs for Dengue

The World Health Organization promotes a strategic approach called the Integrated Vector Management (IVM), which involves the control of vectors transmitting dengue. IVM is defined as “a rational decision-making process for the optimal use of resources for vector control” [12]. The IVM strategy includes five main fundamentals: (1) Advocacy, social mobilization and legislation, (2) collaboration within the health sector and with other sectors, (3) integrated approach to disease, (4) evidence-based decision and (5) capacity-building. The most appropriate vector control measures should be implemented based on the indigenous ecology, behavior of the mosquito species in question, funding obtainable for its implementation, cultural conditions in which control programs are executed, the practicability of executing control programs on time and ensuring adequate coverage. Types of vector control activities include: Environmental which involves source elimination, chemical which involves the use of insecticides including larvicides and adulticides and biological which involves the use of biologic agents [12]. *Ae. aegypti* density surveillance is imperative in defining dynamics linked to transmission, sustainable methods in the control measures will detect any increase in the density of the vector. The indicators that are mostly used are house index (HI) which is the percentage of houses that are infested with larvae and/or pupae, container index (CI) which is percentage of water-holding containers infested with larvae or pupae and breteau index (BI) which is the number of containers positive per 100 houses inspected. The pupa index (PI) which is the number of pupae per house inspected is used for pupae surveys [12].

3.4 Mosquito Control in Malaysia

The vector control program in Malaysia was started in 1983 and is directed at controlling seven vector borne diseases; malaria, dengue, yellow fever, scrub typhus, filariasis, Japanese encephalitis and plague. The dengue control unit is under the vector borne diseases section of the disease control division of the Ministry of Health in Malaysia [31]. Chemical control of dengue vectors is done for both adult and larvae mosquitoes. The adulticides used are permethrin EC-20,000 liter, permethrin EW-10,000 liter and Malathion TG-15,000 liter. The space spraying method is used involving two cycles of space spraying for every notified case. The larvicides used are Temephos SG-11,000kg and Bacillus thuringiensis israeliensis (Bti) WG; they are applied by direct application misting every 3 months for temophos SG and biweekly for Bti. According to the Malaysian ministry of health workshop on management of vector control programs, environmental control for dengue vectors is done majorly using source reduction through community participation in a program called “clean-up campaign”.

Table 1. Showing reported number of cases, deaths and case fatality rates (CFR) of dengue, from Australia, Viet Nam Singapore, Philippines, Malaysia, Lao People's Democratic Republic and Cambodia. Epidemiologic update on the dengue situation in the western pacific region, 2011 western pacific surveillance and response

Country	2007			2008			2009			2010			2011		
	Cases	Death	CFR (%)	Cases	Death	CFR (%)	Cases	Death	CFR (%)	Cases	Death	CFR (%)	Cases	Death	CFR (%)
Australia	316	0	0	56	0	0	1401	0	0	1171	0	0	820	0	0
Cambodia	39851	407	1.02	9542	65	0.68	11699	38	0.32	12500	38	0.30	15980	73	0.46
Lao People's Democratic Republic	4943	4	0.08	4.149	21	0.51	7214	12	0.17	22929	46	0.20	3.905	7	0.18
Malaysia	48846	98	0.20	49335	112	0.23	41486	88	0.21	46171	134	0.29	19884	36	0.18
Philippines	55639	533	0.96	39620	373	0.94	57819	548	0.95	135355	793	0.59	125975	654	0.52
Singapore	8826	24	0.27	7.031	10	0.14	4497	8	0.18	5363	6	0.11	5330	6	0.11
Viet Nam	104393	88	0.08	96451	97	0.10	105370	87	0.08	128831	55	0.04	69680	61	0.09
Total	262814	1154	0.44	206692	678	0.33	229486	781	0.34	35231	1070	0.30	241574	837	0.35

**Source: World health organization western pacific regional office based on data provided by the member states*

**Dengue surveillance and reporting systems vary by country*

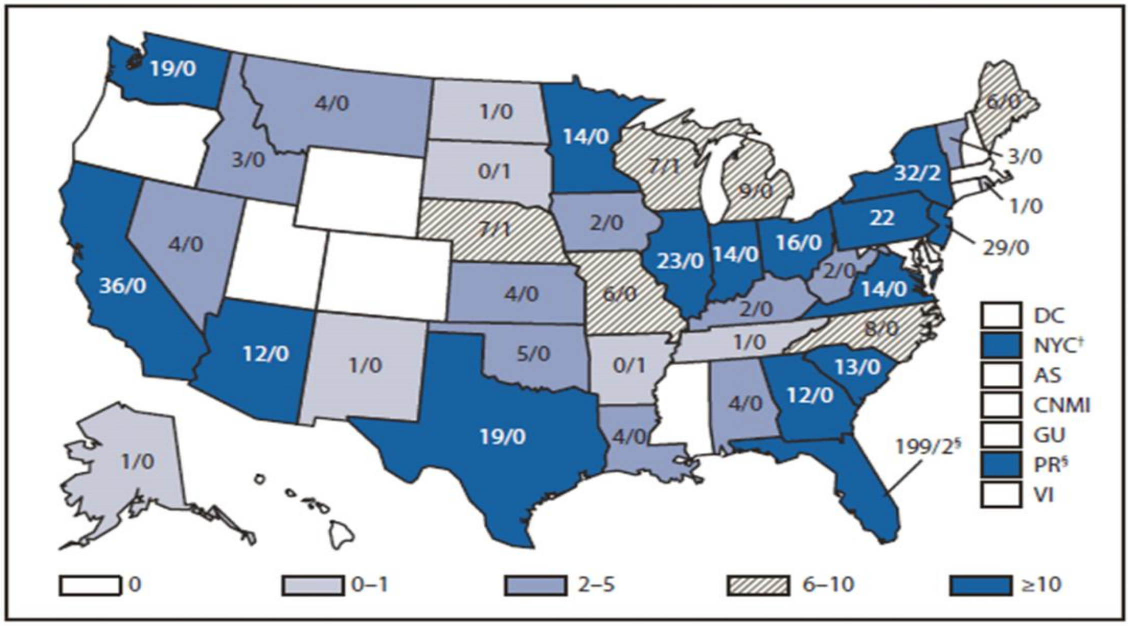

Fig. 2. Dengue in the U. S. showing cases of dengue fever and severe dengue fever cases in 2010. (summary of notifiable diseases–united states. morbidity and mortality weekly report (MMWR), retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5953a1.htm)

Dengue vector control is ranked number one based on Malaysia's national policy and as of 2008, about MYR6million (U.S. $17 million) was allocated for the control program [31]. There are three legislation and laws that govern vector borne disease control programs in Malaysia: (a) "Destruction of Disease-Bearing Insects Act 1975 (Act 154)" (b) "Prevention and Control of Infectious Diseases Act 1988 (Act342)" and (c) "Local Government Act 1976 (Act 171)". The enforcement of the Destruction Disease-Bearing Insect Acts (DDBIA) focuses on discovering larvae during *Aedes* species survey in neighborhoods; if larvae is found, the home occupier or owner is handed a warning and if they do not change the unlawful conditions, a court action will be taken and such individuals will be fined. This illustrates that the Malaysian Government's legislation helps to ensure good control practices [32]. This falls under a control approach known as source reduction, which involves removal or permanent destruction of mosquito breeding sites [33]. A study by Tham Ah Seng on legislation for dengue control in Malaysia in 2001 showed that there was a significant reduction in cases of dengue in the year 2000, which recorded 7,118 cases, as compared to the year 1999, which recorded 10,146 cases; this was as a result of the enforcement of the DDBIA [32].

Community-based dengue vector control method using the Communication for Behavioral Impact (COMBI) tool, a behavioral-focused social mobilization and communication program for communicable diseases prevention and control, was integrated into dengue control programs in Malaysia. In a cross sectional study carried out in Selangor to measure the efficiency of COMBI, it was reported that the program was only effective during the time it was being implemented [34]. Another study conducted in the state of Selangor showed that Bti did not cause any unwanted effects on non-target organisms like birds and fish found in the environment. Containers for animal feed that could hold water were also treated with Bti and there were no reports of deaths of the animals, further showing the safety of using Bti in the environment [35]. Other methods like Ultra Low Volume (ULV) fogging or spraying with insecticides and the use of larvicides work but have low effectiveness. Even when used judiciously, they have not been seen to stop epidemics of dengue in endemic areas. A study in Pahang, Malaysia showed that the use of genetically sterile males could be more effective as these modified mosquitoes could survive and be dispersed in the environment [36]. The principal legislation for the regulation pesticides is the Pesticides Act of 1974 industry; it regulates the use, sales and storage of pesticides. Malaysia has a relatively strong passive surveillance system for severe dengue and a less strong active surveillance for dengue fever, which, plus the asymptomatic illness, is most likely responsible for transmission [31].

3.5 Mosquito Control in United States

Mosquito control programs started in the U. S. as far back as the 1900s. The initiation of DDT and its effectiveness in mosquito control in the period after the World War II years showed that eradicating *Ae. aegypti* prevented yellow fever outbreaks. PAHO in 1946 started a program for the Americas using DDT to eradicate *Ae. aegypti*, which proved to be successful. Consequently epidemic dengue cases reduced and disappeared in most nations in the Americas [37]. Mosquito control programs (MCPs) were established and function to safe-guard people from vector-borne diseases [38]. In the U.S. government agencies and the public both have a role to play in mosquito control. The Centers for Disease Control and Prevention (CDC) and the Environmental Protection Agency (EPA), with the three tiers of government (federal, state and local), work together to combat and prevent mosquito borne diseases. The CDC plays a role in monitoring potential outbreak sources and actual outbreaks and serves as a consultant in prevention and control of such outbreaks. The EPA ensures that local and state mosquito programs and departments have mosquito control agents and equipment that do not pose harm to the environment or individuals. The EPA also educates the populace on basic control methods such as eliminating stagnant water that would otherwise serve as sites for breeding for the mosquitos; they also make sure insecticides are used as directed [33]. State and local government agencies perform an important role by providing information to environmental and medical surveillance networks and by managing programs that are involved in public education involving mosquito population control. The public is engaged in the use of door and window screens and encouraged to wear appropriate clothing and mosquito repellents when visiting highly populated mosquito areas [33].

Current mosquito control programs in the U. S. are multidimensional and comprised of source reduction, adult and larval mosquito control and surveillance [33]. Source reduction is comprised of elimination of mosquito habitat (containers, automobile tires and sanitation) and adjusting aquatic habitats permanently (e.g. managing marshes, stored or impounded water) to stop the vectors from breeding [33]. Biological control methods involve using the Gambusia fish in ponds and ditches to consume larvae of the mosquitos and larvicides (biological like Bti or chemical like DEET, temephos and pyrethroids) are often applied to aquatic habitats. Temporary measures of vector control involve treating breeding sites to eliminate larvae and aerosol spraying (ULV) by ground or aerial equipment to eliminate both adult and larvae [39]. Surveillance plays an important role for mosquito control and involves the use of topographic maps to evaluate larval populations, studying habitats by air and aerial photographs. Mosquito traps are also employed, bite count records are kept and reports of complaints from the public are collected. Records are kept seasonally and measured alongside weather records so as to forecast larval occurrence and flights of adults. The United States Environmental Protection Agency uses the Integrated Pest Management (IPM), which “is an ecologically based strategy that relies heavily on natural mortality factors and seeks out control tactics that are compatible with or disrupt these factors as little as possible” [33]. It involves the use of pesticides in a resource management method only as required based on surveillance results [33]. The Floridian Mosquito Control Program (MCP) which is a tax-based region can make independent decisions from the county government officials and are supervised by a board of commissioners [38]. The MCP staff work on a daily basis by carrying out adulticiding, larviciding and source reduction to make sure mosquito population levels are such that the quality of the life of the human population in such areas are not threatened. Record, tracks and maps of vicinities that have been treated are documented and conveyed to the Florida Department of Agriculture and Consumer Services (FDACs), which is the body responsible for the regulation of use of pesticides [38].

4. DISCUSSION

Dengue control programs have been shown to be differentially successful in both Malaysia and the United States and they both have been relatively effective and efficient mosquito control programs with strong policies backing them, however, these two countries have different organizational structures. Fig. 3 shows the organizational diagram for mosquito control in Malaysia. Dengue control unit is under the vector borne disease section in the disease control unit of the Malaysian Ministry of Health. Fig. 4 shows the organizational diagram for mosquito control in U.S. for both the CDC and EPA. Both countries also participate in control activities involving surveillance, environmental manipulation, biologic and chemical control, public education, activity reports, training, inter-sector collaboration and applied local research. All this can be summarized in the WHO strategic approach called the Integrated Vector Management [12].

Other countries have also had successes in controlling mosquito-borne diseases. Cuba for instance has an *Ae. aegypti* infestation vector index below 0.5 and has recorded no deaths due to dengue in the past few years. The Ministry of Public Health of Cuba made the control and eradication of *Ae. aegypti* a priority and also ensured full community participation. This was done using preventative measures such as sanitation and source control, chemical control with Temephos, biological control using larvivorous fish and BTI, health education, entomological surveillance, all backed up by strong legislation [40]. On the Madeira Island of Portugal which experienced an autochthomous dengue outbreak in October 2012 as a result of the expanding *Ae. aegypti* population, the emergence of insecticide resistance was noted to be a hindrance to vector control efforts in this part of the world [41].

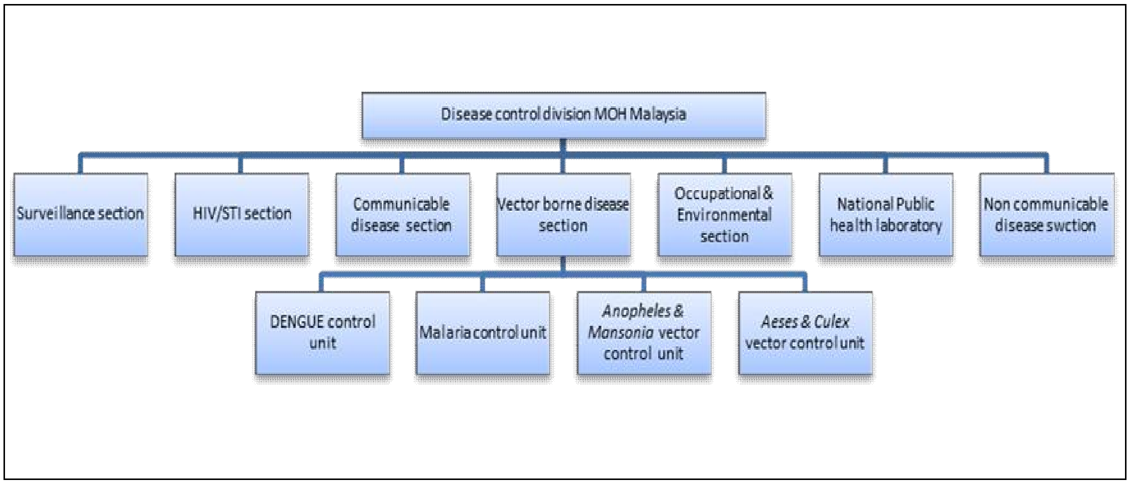

Fig. 3. Organizational diagram for mosquito control operations in Malaysia (MOH Malaysia 2008)

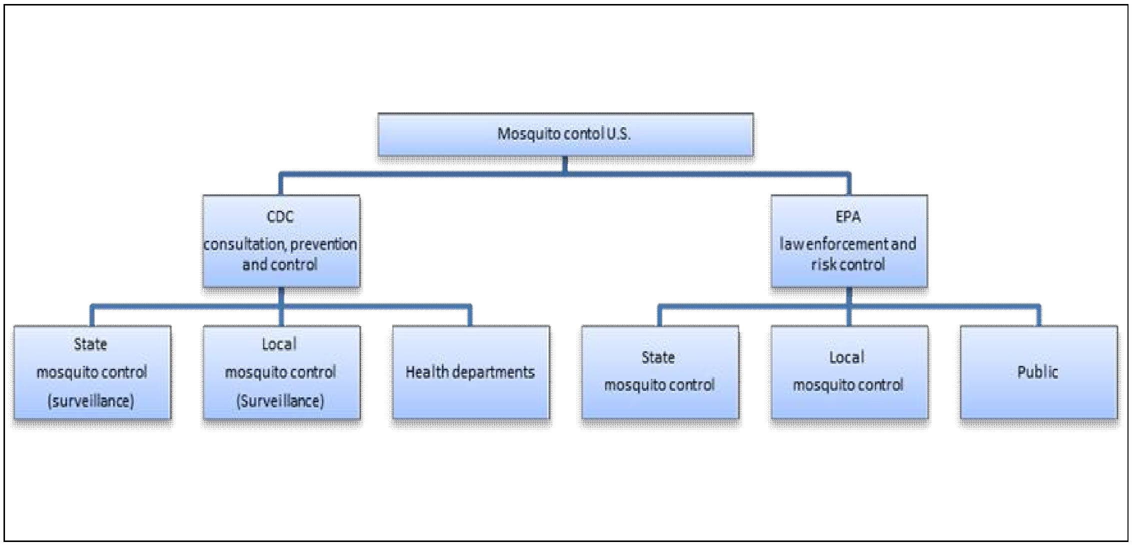

Fig. 4. Organizational diagram for mosquito control operations in United States

5. CONCLUSION

Temperatures during the summer period in the southern United States where dengue vectors are found are higher than most tropical country parts where dengue is present. In a study by Reiter et al. [42], comparing the incidence of dengue fever in Mexico and in Texas along the Texas-Mexico border, it was seen that the incidence of dengue was higher in Mexico despite the closeness of the two areas and the similar climatic condition; this then ruled climate out as a factor. It was noted that *Ae. aegypti* was closely linked with where people live, as it goes in to take a blood meal when the human hosts are resting. Given this perspective, shortage of air-conditioning was linked to transmission of dengue. About 85% of Texan homes have air-conditioning and this applies to most parts of the United States. Individuals living in air-conditioned homes usually have their windows and doors shut in low-, middle- and high-income residential areas, which were different in a developing country such as Mexico and probably Malaysia, where people normally leave doors and windows open even during the day. This shows that environmental factors like air-conditioning and people's behavior affect how mosquitos and humans interact; concluding that dengue prevalence in comparison to a developing country like Mexico is largely due to economic factors. In a study by Mulligan et al. [43], it was seen that poverty and some of its indicators, such as poor urban planning and lack of sanitation, are strong determining factor in the high incidence of dengue fever in dengue endemic countries. It was also noted that dengue is not a disease of the poor, as it affects low-, middle- and high-income individuals. Hence the high incidence can be attributed mainly to poor urban planning, poor physical conditions of homes and low income, while sanitation, access to water, overcrowding in homes did not show a strong correlation with high rates of dengue fever. Malaysia has a relatively strong passive surveillance system for severe dengue and a less strong active surveillance for dengue fever; their laboratories have the capability to provide an active laboratory based surveillance program, which is used to predict in advance epidemic patterns during seasons of peak transmission [31]. Mosquito control in Malaysia is mainly an epidemiological monitoring during peak periods of transmission of dengue and other mosquito-borne diseases [31].

In the U.S. each county has a mosquito control program department, which actively monitors mosquito numbers on a weekly basis. This is done by trapping, counting and speciating the mosquitoes; when the numbers go up, subsequent actions of source reduction are put in place [33]. Most of the mosquito control for dengue and other mosquito-borne diseases are done in the United States is mainly entomological and is performed on a daily [38].

There are existing gaps in dengue vector control practices when comparing control programs in developing versus developed countries and further research needs to be done to determine what they are and other reasons for these gaps. Interventions need to be directed towards eliminating these gaps in dengue vector control to lead to a reduced incidence in these populations. Interventions may need to focus on policies on urban planning, educating the population on practices regarding human behavior and habitation and more emphasis should be placed on developing an active dengue surveillance system with a daily or as frequent as possible entomological monitoring methods. More attention and finances need to be put in place to developing an efficient and efficacious dengue vaccine in the nearest future for optimum prevention of this mosquito borne disease.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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