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Vector-borne diseases: Prevalence, impacts, and strategies to address disease burden and threats

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Abstract
India and sub-Saharan Africa are accounted for almost 80% of the vector borne disease (VBD) cases reported globally according to a recent WHO report. According to a WHO assessment, 1.25 billion individuals in India are at risk of contracting VBD. India is one of the countries where high treatment failure rates are evident but this can be responded by effective implementation of the vector control strategies (VCS). VCS such as the suppression of vector populations via physical, biological, microbiological, chemical is vital for drop in VBDs. As new drug development is a slow and costly process, the need of the hour is to suppress the vector population by implementing those strategies which are rationale, reasonable and can easily be implemented in India. In this article, we review the current knowledge and potential impacts, prevalence; various control strategy and their applicability on mosquito as well as VBD in India.

Keywords: Mosquito, vector-borne disease, prevalence, impact, control strategy

1. Introduction

If we can't stop mosquitoes, we can't prevent the disease from spreading Mosquitoes are most important pest in our life. At worst, they're a menace to humanity, responsible for the death of millions of humans around the world every year through the inadvertent spread of the parasites they carry. In our country, Climate, rapid urbanization, a growing population and lack of sanitary waste and water disposal have allowed these disease-causing vectors to grow uninterrupted [1]. In big metropolitan cities, due to population explosion, there are more and more people reside within the same infrastructure or in close vicinity with each other, and this has created more waste, which is not disposed off properly. Whereas, in villages, due to improper waste water management, water logging made the mosquitoes much more comfortable in human habitats. Female mosquitoes lay their eggs in artificial containers with a bit of standing water - flower pots, vases, tires, buckets, planters, toys, birdbaths, empty garbage cans, lids [2]. This is why the mosquitoes have a very good ground for breeding.

2. Materials and methods

The available published and unpublished mosquito research were gathered and analysed. Articles published between 1990 and July 2021 was culled. In order to find studies on the prevalence, strategy, and impact of vector borne disease, related articles were searched using search engines from the following electronic bibliographic databases: PubMed, Google Scholar, National Vector Borne Disease Control Programme (NVBDCP), WHO report, DRDO report and Science Direct literature. By manually searching Google and looking through reference lists, several papers were discovered. Articles were searched indefinitely. The search terms "Mosquito diversity," "prevalence," "Impact," and "Strategy" were used in India to discover publications.

3. Results and Discussion

3.1 Climatic diversity and Mosquito prevalence in India

India is a very big country with different types of climatic regions.

The Western Ghats, Malabar Coast, southern Assam, Andaman and Nicobar Island experience tropical monsoon climate, whereas, in Karnataka, central Maharashtra, some parts of Tamil Nadu and Andhra Pradesh the climate is tropical semi-arid. Western Rajasthan, tropical desert regions of Punjab, Haryana and Kathiawar experience subtropical semi-arid climate. Most of the North and Northeast India experience subtropical humid environment. In Himalayan region, the climate is temperate and alpine [1].

Higher temperature, rainfall and humidity are essential for mosquito breeding. An increase in temperature produces more mosquito-friendly habitats, resulting in larger number of mosquitoes, it has also been shown that mosquito populations increase with higher spring soil moisture levels; snowmelt and spring rain all provide sufficient standing water to allow the breeding of mosquitoes, even in typically "dry" areas [3]. It has been reported that mosquitoes can withstand temperature as high as 40 ºC and as low as 10 ºC. Further, in drought prone areas of our country, the water sources may be scarce but these are dirtier and therefore appealing to mosquitoes. There aren't enough water sources, mosquitoes, which are responsible for a number of mosquito-borne diseases are forced to share the scarce resource [4].

3.2 Mosquito diversity in India

One of the mosquito biogeographic hotspots in the world is considered to be India. In terms of mosquito biodiversity, India comes in fifth place, behind Brazil, Indonesia, Malaysia, and Thailand. Since there is no reliable collection of data on the field, it is exceedingly impossible to estimate the number of mosquito species and subspecies that exist in India. However, one review article state that Indian mosquito fauna comprises 404 species and subspecies belonging to 50 genera and 2 subfamilies, Anophelinae and Culicinae. All the 400 mosquito species found in the country are carriers of diseases [5]. Most commonly found mosquito species in India includes– *Anopheles*, *Aedes*, *Culex*, and *Mansonia* (Table 1).

3.3 Menace of Mosquito borne diseases in India

Major public health issues in our region are vector - borne diseases such lymphatic filariasis, dengue fever, chikungunya, acute encephalitis syndrome (AES) and malaria [6]. Among these, malaria and dengue fever are the predominant infections and are spread across the country. Malaria is transmitted from man to man by the female *Anopheles* mosquito, one of the most capable vectors of human disease. The spreading of malaria in India has been linked to *A. culicifacies*, *A. fluviatilis*, *A. philippinensis*, *A. minimus*, *A. stephensi*, *A. leucosphyrus* and *A. sundaicus* [7].

Malaria is a potentially life-threatening parasitic disease caused by *Plasmodium* parasites (*P. vivax*, *P. falciparum*) and is a public health problem in several parts of the country. About 95% of the nation's population lives in malaria-endemic areas, and 80% of malaria cases recorded there are limited to those areas, and 20% of the population lives in tribal, mountainous, tough, and inaccessible areas [8]. India is one of the top 15 nations in the world for malaria infections and fatalities, according to the WHO 2017, World Malaria Report. India had the lowest rate of malaria cases detected by its monitoring systems, according to the WHO survey, despite having a significant disease burden. But still our country accounted for 4 percent of the global burden of malaria morbidity and 52 percent of deaths outside of the WHO African Region [8].

In 2017, according to NVBDCP, there were 6, 70,000 cases of malaria with 84 reported deaths. However, considering the lost malaria cases, the data set is not reliable. The WHO has also called on India to strengthen its disease surveillance network, urging the government and private healthcare providers to have closer communication. This would allow for a more reliable count of cases, which remain massively unreported [8, 9].

Dengue is another fastest growing mosquito-borne viral infection. The four serotypes of the dengue virus, which is a member of the Flaviviridae family and is transmitted by the bite of infected *Aedes aegypti* mosquitoes and sporadically by *Aedes albopictus* mosquitoes. When a female *Aedes* mosquito bites a human, the infection is spread. From moderate asymptomatic disease to severe deadly dengue hemorrhagic fever/dengue shock syndrome, it can cause a wide range of illnesses. One of the scariest worries for the nation is this virus spread by mosquitoes. In 2017, according to NVBDCP, there were 1, 53,635 cases of dengue with 226 deaths in our country [10]. Highest incidence of dengue cases was in Tamil Nadu followed by Kerala, Karnataka, Punjab, Odisha, West Bengal and Delhi [9].

The virus that causes chikungunya fever infects individuals when infected *Aedes aegypti* mosquitoes bite them. A member of the Togaviridae family is the chikungunya virus. Usually, there is no danger to life. With a peak between the months of July and August due to the high vector population at this time, chikungunya cases begin to develop in the post-monsoon season period, which is from the month of May onward. Chikungunya is a disease that affects the states of Andhra Pradesh, Karnataka, Maharashtra, Madhya Pradesh, Tamil Nadu, Gujarat, and Kerala. 62,268 instances of chikungunya were reported in our nation in 2017, according to NVBDCP. Karnataka tops the list with 31,644 cases followed by Gujarat and Maharashtra with over 7600 cases [10].

Another viral infection known as Acute Encephalitis Syndrome (AES), which includes Japanese encephalitis, is characterised by an immediate onset of fever and clinical neurological symptoms such mental loss, dizziness, psychosis, or consciousness. AES virus is a member of the Flaviviridae family. It is spread by the bites of female mosquitoes, particularly those of the *Culex tritaeniorhynchus*, *Culex vishnui*, and *Culex pseudovishnui* groups, which are infectious. Characterized by high case-fatality rate, the disease occurs in seasonal outbreaks every year, taking a heavy toll of life, especially of children below 15 year of age. In 2017, 13,672 cases of AES with 1062 deaths were reported across the country. Uttar Pradesh was at the top of the list With 4724 cases and 654 fatalities. While Japanese encephalitis virus is the leading diagnosed cause of acute encephalitis, other causes include enteroviruses, scrub typhus, measles and other viruses circulating in the local area [11].

Elephantiasis, also called as Lymphatic Filariasis (LF), is a severe and incapacitating condition brought on by the nematode worms *Wuchereria bancrofti* or *Brugia malayi* and spread by the widespread mosquito species Culex quinquefasciatus and *Mansonia annulifera/ M. uniformis*, respectively. Patients with lymphoedema experience recurrent infections that frequently result in high fevers and excruciating pain because of the compromised lymphatic system. Despite not being fatal, filariasis weakens the affected people, their families, and the epidemic societies. It also places a heavy social and financial strain on them [14]. WHO data reveals that one billion people in over 54 countries are at risk of developing the disease. India, Indonesia, Nigeria and Bangladesh contribute to 70% of the infection worldwide. India accounts for 40% of the world's LF burden. There may be up to 31 million microfilaraemics, 23 million symptomatic cases, and over 500 million people at risk of getting the disease at this time in the nation [13, 14].

3.4 Mosquito economics
According to government sources and documents, in 2018 to 2019, India is poised to raise its public health spending by 11% to $8.2 billion, which is one of the lowest proportions in the world. WHO has urged its members, including India, to concentrate on mosquito control in response to the sharp increase in the socioeconomic burden brought on by vector-borne illness like Dengue, Malaria, Chikungunya, etc. [8, 9].

3.4.1 Malaria
The United Nations (UN) estimates that India's socioeconomic cost from malaria alone is estimated to be over $1.94 billion annually, with 95% of the population living in areas where the disease is prevalent. A strategy for strategic malaria action through 2022 has been published by the Ministry of Health and Family Welfare, with the goal of eradicating the illness by 2030. The National Strategic Plan (NSP) for malaria eradication by 2030 has been published by the Indian government. It covers the years 2017 through 2022. The programme will be included in the NVBDCP under the National Health Mission [8] (Table 2). As per the plan, a total of INR 9512 crore will be provided during 2018-22 for malaria eradication in India of the total funds required, around 46% will be used to meet out programme-specific human resource requirement and only 27% is allocated for the implementation of preventive strategies such as distribution of nets and indoor residential spraying. 14% of the funds are allocated for treatment and diagnosis. Monitoring and evaluation will cost close to 4% of the budget while the spending on communication and outreach will be close to 2% [10].

3.4.2 Dengue and Chikungunya
Dengue, one of the devastating diseases transmitted by the *Ae. aegypti* mosquito, is also taking a toll on the Indian economy. *Ae. aegypti* mosquito is also responsible for recent chikungunya outbreaks in the country, and is also the primary carrier of the Zika virus. According to estimates from the UN agency, the growing rates of dengue alone result in over $1 billion in economic expenditures per year, including direct and indirect costs like lost output and medical expenses. As per State of India’s Environment 2019 in figures, only INR 505 crore was allocated (2017-2020) to tackle the challenge of vector borne diseases, for dengue and chikungunya, about 155.97 crore were allocated [13].

3.5 Mosquito life cycle, control strategies and their efficacy
Preventing or reducing the transmission of mosquito borne diseases depends entirely in controlling the mosquito. For efficient control, transmission control activities should target mosquitoes in its immature (egg, larva, and pupa) and adult stages in the household and immediate vicinity [14] Without understanding the life cycle of a mosquito (Figure 1), it is very difficult to control them. Life cycle of mosquitoes composed of several stages [12]. It commences with lying of eggs by female mosquito in or around water. These eggs are attached to one another, forming a raft [3]. After 24 to 48 hours, the eggs hatch and release the larvae. Larvae remain aquatic, hang horizontally below the water surface and breathe air. The larvae of *Anopheles* lack a syphon and lay parallel to the water's surface to breathe through an aperture. *Mansonia* and *Coquillettidia* larvae cling to plants to get their source of oxygen. The larvae consume organic material and microbes found in the water. As they get older, larvae shed their old exoskeleton and develop a new one. Instars are the phases that occur in between these moults. Larval stage consists of four instars [1]. The larval stage lasts between 4 and 14 days, depending on the species, the temperature of the water, and the availability of food. A pupa develops during the fourth moult of the larva. Pupae are mobile throughout the pupal stage of development, responding to changes in light by flipping their tails and migrating towards the bottom or safe regions. Pupae are in a resting, non-feeding stage of development. Between 1.5 and 4 days pass during the pupal stage until the skin of the pupa breaks along the back, allowing the newly created adult to gently emerge and settle on the water's surface. The freshly emerging adult spends a brief period of time floating on the water's surface to allow all of its body parts to harden and dry. Before it can fly, the wings must fully dry and spread out. Blood feeding and mating does not occur for a couple of days after the adults emerge [12]. Basically four types of mosquito control strategies are used *viz*. Physical control, Biological, Microbial and Chemical Control.

3.5.1 Physical control
Physical control is one of the most effective mosquito control strategy available. The physical control methods primarily targets mosquitoes in their larval stage. Here emphasis is given on eliminating, or significantly reducing, mosquito breeding sites. There are many types of mosquito breeding sites such as standing water in rain gutters, old tires, buckets, plastic covers, toys or any other container, irrigated agricultural land, industrial waste ponds etc. which can be reduced by physical control strategy [12, 14].
It should be highlighted that mosquitoes may breed in as little as two tablespoons of water, and that under the best conditions for breeding, those 2 tablespoons of water only require to be present for five days in order for mosquitoes to mature into adults [16].
Container breeding areas can be avoided by properly disposing of the items involved, covering them, or toppling them over so that no water collects. In case of rain gutters, irrigated agriculture land, waste water ponds etc, proper water management, land preparation, adequate and periodic drainage can control mosquitoes in these types of sources. Filling of mosquito larval habitats with sand can be used to eliminate the breeding ground for mosquitoes. Frequent tracking of species categories, larval and adult size of population, and breeding places provides vital data that may be used to pinpoint when and where intervention might be required. If properly implemented physical control techniques can virtually eliminate the need for pesticide to eliminate the mosquitoes [15, 16].
Although it is beneficial to control the mosquitoes at the larval stage, but sometimes it is not feasible or successful.

Control of adult mosquitoes may be necessary when high mosquito abundance creates a threat to public health. Adult mosquito control methods include physical control such as using mosquito traps, mechanical barriers and Vegetation Management [14].

Since a few years ago, electric mosquito traps, also known as bug zappers, have already been heavily promoted with the premise that they may protect users from mosquito bites [17]. There are several products on sale that make the promise to draw, deter, or eliminate outdoor mosquito infestations. The effectiveness of these gadgets is questionable, though. Apart from insect electrocutors, mosquito nets have also been developed. The toxic vapours of carbon dioxide, temperature, and humidity that are released by these traps to imitate a prospective mammalian host are frequently mixed with another attractant, like as octanol, to make a mosquito attractant [18]. Once the mosquitoes are attracted to the trap, a suction system pulls them into a net or cylinder, where they die from dehydration. However, scientific data relative to the effectiveness of these devices do not exist; different species of mosquitoes respond better to different attractants. In addition, these mosquito traps are quite expensive. Mosquito traps able to lure mosquitoes via the Ultraviolet (UV) light have also been investigated. These mosquitoes trap uses electricity to UV light up the light inside the trap. When mosquito's reaches close to the device, they are sucked into the trap using a fan. These mosquito traps do not cover that large of an area and works better in an enclosed space. The coverage area of mosquito traps may range from 300 square feet to 1.5 acre, depending upon the mechanism and size of the device. Although mosquitoes may bite indoors as well as outside, it is essential to install window and door screens and seal all holes that exist between the doors, and windows within the dwelling. Use of mosquito nets is especially important for protecting a person from getting mosquito bites [19].

Other physical control strategies include preventing the development of the eggs into adult mosquitoes, by reducing the sources of breeding; alter the habitat characteristics such as pH or vegetation load so that it becomes unsuitable for mosquito breeding [7]. These anti-larval methods are not only easy and affordable, but also environmentally responsible. However, it must be noted that, physical control techniques that modify existing land and aquatic habitats also have the potential to negatively impact on the surrounding environment [20].

The Kochi Corporation in Kerala reported on a creative and economical technique for lowering mosquito populations when they are in the larval stage. Here, the water in canals and still ponds became more salinized. Mosquito larvae cannot grow in the canal and other stagnated water bodies if salinity is increased. It was observed that when salinity level reaches 30 parts per thousand (PPT), mosquito larvae cannot survive beyond 3 hours; at 15 PPT, mosquito larvae are dead in 12 hours and at 60 PPT they perish within the hour [21].

3.5.1.1 Advances in physical control of mosquitoes

3.5.1.1.1 The photonic fence

The photonic fence functions by first identifying a passing insect with the use of sensors, then determining its wing beating frequency, morphology, and speeds. Since only female mosquitoes bite people and must therefore be eliminated, the internal computer programme of the fence can even distinguish among male and female insects. An invisible infrared laser is directed at a passing insect by the fence once it determines that it is a legitimate target, and just enough photonic energy is delivered to stop the flying insect in its tracks. The system, which does not endanger humans or animals, is calibrated to destroy its prey using the least amount of energy possible and so can run on solar power. Pests travelling through a death zone that stretches up to 98 feet (30 metres) horizontally and 10 feet (3 metres) vertically are effectively shot down by the virtual fence [22].

3.5.2 Biological control

"The enemy of my enemy is my friend."

Introducing of insects that feed on, parasitize, fight with, or somehow deplete numbers of the target species is the basis of biological management. These include larvivorous fish species, predatory copepods, entomopathogenic nematodes, friendly mosquitoes etc. [13].

The primary biological control is the larvivorous mosquito fish. The mosquito fish species found in our country includes *Gambusia affinis* and *Poecilla reticulate* (surface feeder), *Danio rerio* and *Rasbora daniconius* (subsurface feeder) etc. The mosquito fish preys on mosquito larvae thereby controlling mosquito populations [13].

When introduced into a mosquito breeding source, the mosquito fish quickly adapts, multiplies and controls mosquitoes in a given area. A single, fully grown gambusia fish eats about 100 to 300 mosquito larvae per day [23]. Gambusia fish is very effective against *Anopheles* and *Culex* species. However, because mosquitoes can often reproduce more quickly and in bigger populations than biological controls, it is important to make sure that there will be enough prey for the predator. Despite this, biological controls are an important tool in controlling mosquitoes and can be employed to great effect in certain situations. When compared to the price of fogging devices and larvicide oil sprinkling in drains, the cost of importing larvivorous fish is comparatively modest. The fish has a cheap maintenance cost because it just eats mosquito larvae and doesn't need any additional food. The option is eco-friendly too compared to other methods. There should only be larvivorous fish utilised since foreign species might escape into natural areas and endanger the local wildlife [24].

Copepods are a remarkably diversified collection of tiny crustaceans that are abundant practically anywhere there is fresh or salt water. Recently, they have drawn interest for biological mosquito control because studies have found that some species of Copepods devour mosquito larvae. The cyclopoid *mesocyclops aspericornis* is a generalist predator that preys on mosquito larvae and fish larvae. Copepods continuously bite their food as it swims by, finishing the entire meal. According to one study, a single copepod may kill 30-40 mosquito larvae every day due to its feeding method. In northern VietNam copepods have been reported to control *Ae. aegypti* mosquitoes. To date, these successes have not been replicated in other countries [24, 25].

Entomopathogenic nematodes and their symbiotic bacterium are exceptionally safe biological control agents**.** These nematodes and their associated bacteria are harmless (non-toxic) to mammals and plants. Once a host has been found, the nematodes enter the larvae through regions of weak cuticle or often natural body holes. Infected juveniles transfer symbiotic bacteria into the insect's blood from their stomach cavity inside the body cavity. In the blood, multiplying nematode-bacterium cause septicemia and kill their insect hosts usually within 48 hours after infection [25].

Friendly mosquitoes are male *Ae. aegypti* mosquitoes that carry a "self-limiting" gene. The progeny of friendly mosquitoes mating with wild females carry a copy of this gene, which stops them from developing into adult mosquitoes. The number of wild pests declines because the progeny do not reach sexual maturity. In an approach to restrict the spread of malaria parasite, scientists from University of California have engineered *friendly mosquitoes* with two ingenious genetic modifications. One set of genes produces antibodies against the malaria parasite that the mosquito carries. These genes make mosquitoes immune to the parasite, preventing them from transmitting malaria. Another set of genes propel the malaria-resistance genes throughout a natural mosquito population. The gene drive replicates itself and the resistance genes from the male chromosome to the female counterpart when a malaria-resistant male mosquito mates with a wild female. As almost all the progeny carries the new genes, the inserted genes are expected to spread rapidly and take over a wild population. So, in principle, a large region could be freed from malaria [18].

Biological control strategies have a number of merits, for example, they do not pollute the environment as done by chemical insecticides; they can self-perpetuate; they are selective which is most important for the balance of the ecosystem; the pest is unable to develop the resistance; cost effectiveness in the inaccessible areas. However, these strategies do have certain demerits: Biological control agents are more susceptible to the environmental conditions than the chemical control; Biological control is a slow process; the process of setting up the biological control system is a costly endeavor; besides larvae, biological control agents could also eat otherwise environmentally useful species; the outcome of the biological control is unpredictable; to develop biological control in field is difficult & sometimes expensive as it requires high qualified scientific staff and it is very difficult to test the host specificity as it takes several years to complete. When a non-native biological agent is used to eradicate a non-native pest species, it might occasionally turn out to be a pest itself [25, 26].

Further, use of genetically modified (GM) mosquitoes as a biological control agent is also associated with number of risk factors. These include: the elimination of one species may give rise to the establishment of another insect species; the newly introduced gene may transfer into another species; the unknown effects of GM insect on human health and the environment; the damage caused to ecosystems may be irreversible [18, 27].

3.5.3 Microbial control

Microbial control is the use of specific microbe that eliminates immature mosquitoes. This strategy is helpful when biological and physical control approaches fail to keep mosquito populations below what is deemed tolerable or when urgent action is required to stop the spread of illness to people. Among various microbial control agents, *Bacillus thrungiensis* (BT) and *Bacillus sphaericus* (BS) are being widely used [14, 26].

When BT bacteria are consumed by mosquito larvae, they harm the gut cells, immediately paralyse them, and then swiftly and effectively kill the larvae. A moderate to heavy dose has been shown to reduce the mosquito population by one half in 15 minutes and the rest within one hour. Over two decades of practical usage of the BT's formulations for mosquito eradication have proven their potency against *Anopheles*, *Aedes*, and *Culex mosquitoes*. The early larval stage, when eating is vigorous, is when BT is most effective. From the late larval stage on, however, when feeding has slowed or halted, BT is ineffective [28].

Mosquito larvae are endotoxified by BS. It is consumed by the larvae as live bacteria. These bacteria can enter through the mosquito larvae intestines into the hemocoel. The BS reproduces and delivers fatal dosages of poison killing the mosquito larvae once inside the hemocoel. Mosquitocidal bacteria are safe to humans and innocuous to the environment. BS as a larvicide is similar to BT, and is even more effective against *Culex* species. It is also effective against *Anopheles* species and has better residual activity in polluted waters by production of binary toxin and mosquitocidal toxins. Unfortunately, it has a limited range of uses since it is not highly efficient against aedine mosquitoes [24, 28].

3.5.4 Chemical control

The fastest way to limit the rapidly expanding mosquito population is by chemical control. Chemical control methods are applied as last resort when physical, biological and microbial control methods fail to maintain mosquito population under control or during an epidemic of mosquito-borne disease when emergency control measures are needed. In chemical control, synthetic, semi-synthetic and sometimes naturally occurring pesticides are used for immediate control of mosquitoes. There are two types of approaches in chemical control of mosquitoes: larviciding and adulticiding [29].

The goal of larviciding is to eradicate mosquito larvae. It is regarded as a relatively safe strategy for preventing mosquito larvae or pupa from developing into adult mosquitoes. Chemical larvicides target mosquito larvae in their breeding habitat before they can mature into adult mosquitoes. Examples of chemical larvicides include organophosphates (Temephos, Fenthion). Organophosphates are neurotoxins. These larvicides are directly sprayed on the mosquito larval habitat. Unfortunately, these larvicides have the following drawbacks: (1) they are poisonous to people and other non-target species; (2) they degrade the aquatic environment; (3) they are expensive annually; and (4) they are susceptible to the development of target resistance [30].

Mosquito growth regulators are also used to control the population of immature mosquitos. These agents mimic mosquito juvenile growth hormone**.** In mosquitoes, juvenile growth hormone production ceases when a mosquito pupates. This allows the mosquito to develop into an adult while in its pupal stage. When these agents are present in the water, the pupae are not able to develop into an adult and the mosquito dies in its pupal stage. Examples of mosquito growth regulators include Methoprene, Pyriproxifen etc. These chemicals are non-repellent and have a long residual effect indoors but degrade fairly quickly outdoors [31].

Pupae and larvae in their late fourth instar are managed using oils and mono-molecular surface coatings. When these materials are spread on the water's surface, the oil expands and covers the entire area. This prevents larvae and pupae from suspending at the surface to breathe. These products are effective for a few hours to a few days, depending on the product. These products may also affect other organisms that do not have gills and breathe at the water's surface. However, these agents are the only products effective against mosquito pupae [32].

Compared to adulticiding, larval control is significantly more effective because it is able to treat larval mosquitoes in extremely high concentrations at their development areas. On the other hand, adult mosquitoes tend to scatter quickly after emergence [33].

In adulticiding, emphasis is on killing adult mosquitos, usually by residual surface treatments or space treatments, when they are present in very high density. Adulticides such as Malathion, Resmethrin and Pyrethrin are wide-spectrum insecticides, with the ability to kill beneficial insects as well as pests, and can also be toxic to vertebrates including fish, birds and mammals. When conditions for adulticiding have been met, these agents are applied via truck-mounted ultra low volume foggers. Both Malathion and Resmethrin or Pyrethrin can be used in these sprayers. Historically, aerial and ground application of these pesticides constituted the primary means of controlling mosquito populations, and large amounts were used annually [33].

There are methods for controlling mosquitoes at different phases for all of the aforementioned strategies. Although these controls can be employed separately, they are frequently considered to be a part of integrated vector management.

3.5.5 Advances in mosquito control strategies

3.5.5.1 Nuclear-based sterile insect technique (SIT)

SIT involves using ionizing radiation to sterilize mass-reared insects of the target pest and then releasing them into nature where they mate with wild insects, resulting in no offspring and, over time, reducing the overall insect population. After the Zika crisis last year, research into SIT's use against *Aedes* mosquitoes has increased. SIT has been used effectively in over 40 countries to combat agricultural pests including diverse fruit flies, tsetse flies, screwworm pests, and moths pests [26].

Long-lasting insecticide-treated bed nets and indoor spraying with insecticide have been the bedrock of malaria control for the last few decades [34]. However, they are an imperfect tool. In many malarias endemic countries, the mosquito is developing resistance to the insecticide. A prospect that is potentially "catastrophic. Researchers at the London School of Hygiene and Tropical Medicine have just announced the results of a new trial which showed that bed nets treated with a mixture of insecticides: a standard pyrethroid and a novel insecticide Pyriproxifen reduced the prevalence of malaria by 44%, compared to a standard bed net treated with the standard insecticide, pyrethroid. The mixture of chemicals disrupted the maturation of eggs in the ovaries of mosquitoes which come into contact with the net. The research also revealed that indoor pesticide spraying with pirimiphos decreased the risk of malaria infection [34] because there are only a few pesticides available, this is definitely good news for attempts to combat malaria.

3.5.5.2 Novel pesticide approach

In conventional practice, mosquitocidal pesticides are sprayed all over the mosquito habitat to kill them. This practice is just like carpet bombing the entire area with pesticides. Agenor Mafra-Neto, a chemist from Integrated Pest Management Company, ISCA Technologies, has developed a special type of bait that might target mosquitoes more directly. Rather than "carpet bombing" entire areas with conventional broad-spectrum pesticides, this breakthrough combines the power of a variety of sweet-smelling flowers and other nectar-producing plants (semiochemical attraction) with the lethal effect of small amounts of insecticide (pyrethroid) to attract vectors to contact or feed on the formulation. As the mosquito picks this poison laden bait, they die instantly. This has resulted in use of far less insecticide per area. This technique is claimed to be highly efficient in killing vectors without affecting humans or non-target insects [13, 35].

3.5.5.3 Contribution of Defence Research and Development Organization (DRDO) in vector control

DRDO has been working continuously to address the problem of mosquito menace. A number of technologies have been developed by DRDO scientists over the years. This will certainly decrease our dependence on technologies developed outside the country.

3.5.5.3.1 Technology for dengue control

An attracticide with "Kill" property has been developed by the Defence Research and Development Organization (DRDO) employing this attractant in conjunction with insect growth regulators (IGR). The females can be effectively lured to deposit eggs in water containing the attractant by the attracticide. Their eggs do not develop into adults; instead, they become larvae. The Municipal Corporation of Delhi independently conducted field tests of the technology in a number of Delhi localities, and the results have proven the attracticide's efficacy in reducing *Aedes* population. In India, this technology has been patented. Patent in USA, UK, Japan and many other countries under Patent Cooperation Treaty (PCT) has been applied for. Technology transfer to a US-based firm is under progress [36]. A deadly death trap based on the lure-and-kill method has been created by scientists at the DRDO to kill *Aedes* mosquitoes that spread dengue [37]. Research found that the gravid female mosquitoes are attracted to treated water by fruity smell of propyl octadecanoate and killed by minute quantity of insecticide as soon as they touch water for egg laying [38]. The results are promising under laboratory conditions, which will undergo rigorous testing under semi field and field conditions before being deployed for control dengue mosquitoes in various endemic locations in the country.

DRDO isolated and identified an oviposition attractant pheromone, C21 hydrocarbon from the larval conditioned water of dengu vector *Ae. aegypti*. Then the attractant combined with IGR compound, produced an effect of luring and killing [39].

DRDO has patented 2-phenylacetamide compounds from plants for the preparation of insect repellents in the form of creams, patch, sprays or other formulations [40]. Scientists at DRDO developed SAFE, an herbal based mosquito repellant cream and spray. One application of SAFE gives protection for several hours (4 hours for mosquitoes and 8 hours for leeches (Applicable to Army in Jungle Operations). This product is non irritant and non-toxic. Defender net produced by Defence Research Laboratory (DRL), Tezpur, Assam, makes " make In India " dream come true for long lasting insecticidal mosquito net (LLIN) manufacturers. This mosquito net is highly effective due to synergism Piperonyl butoxide (PBO). This product is highly effective even after 20 washes and up to 6 years. It protects against mosquito bites while sleeping [41, 42]. DRDO scientist at the Defence Research Laboratory (DRL), Assam, developed "Dentrap" which is trapping device for dengue, chikungunya, encephalitis, filariasis vectors and Toxmos, which is an aerosol formulation for application onto fabrics and personal protection from mosquitoes and other biting insects [27].

3.6 Relevance of various control strategies

Eradication of disease-causing vectors always constitutes an extraordinary goal as it takes into consideration both means and economy. Table 3 represents our views about various mosquito control strategies and their relevance with respect to India.

3.7 Tables and Figures

Table 1. Vectors of mosquito diversity in India.
Table 2. Total cost for malaria eradication in India.
Table 3. Control strategies and their relevance to India.
Figure 1. Mosquito life cycle

Table 1: Vectors of mosquito diversity in India.

Vector		Disease	Habitat	References
Genus	**Species**			
Aedes	*albopictus, aegypti*	Dengue and chikungunya	Container breeder especially man-made containers with clean water and rock pools, streams, canals, containers, floodwater and tree holes.	[3]
Anopheles	*stephensi, vagus, culicifacies, baimaii, fluviatilis, minimus, gambiae, sundaicus, annulariss. l., barbirostriss.l. peditaeniatus, subpictuss.l, jeyporiensis, varuna, nivipes, maculates, philippinensis*	Malaria	Prefer clean and unpolluted water	[13, 30, 34, 43, 44]
Culex	*quinquefasciatus, vishnui, epidesmus, infula, pseudovishnui, tritaeniorhynchus, bitaeniorhynchus, gelidus, whitmoreifuscocephala*	Acute encephalitis syndrome (AES) and West nile virus	Mainly breed in polluted stagnant water and drains.	[35, 36]
Armigeres	*sabalbatus*	Filariasis	Water bodies often polluted and closely associated with human habitation. Cemented tank is one of the breeding habitats.	[14]
Mansonia	*annulifera, indiana, uniformis*	Filariasis and Encephalitis	Ponds and lakes containing certain aquatic plants especially the floating type like *Pistiastratiotes* and water hyacinth	[35]

Table 2: Total cost for malaria eradication in India.

Type of expenditure	2017-18	2018-19	2019-20	2020-21	2021-22	Total
Intervention costs	597.06	751.83	750.68	900.42	1381.25	4381.23
Programme costs	532.85	1435.36	1338.94	1419.20	1496.71	6223.05
Governance & Others	10.65	7.47	12.50	7.35	10.91	48.88
Total costs (crore)	1140.56	2194.66	2102.12	2326.96	2888.87	10653.16

Source: National Strategic Plan Malaria Elimination in India 2017-2022 [8, 9].

Table 3: Control strategies and their relevance to India.

Control strategy	Mosquito species and development stage	Relevance with respect to India	References
Physical Control (Source reduction)	All Mosquito species. All larval stages, adult mosquitoes.	One of the most effective mosquito control strategies. Pollution free, easy to implement and most relevant considering vast area of our country.	[16, 12, 14]
Biological Control (Larvivorous fish)	*Anopheles stephensi, Anopheles culicifacies, Aedes aegypti, Culex quinquefasciatus* larval stages.	Another most effective control strategy with respect to our country. Beneficial for control of mosquitoes in water bodies in tropical monsoon climate regions; subtropical humid regions; tropical semi-arid regions. The cost of introducing larvivorous fish is relatively lower than that of control strategies.	[12, 13, 24]
Microbial control (BT & BS bacteria)	Early larval stage of *Anopheles*, *Aedes*, and *Culex* mosquitoes.	Second line strategy. Effective on mosquitoes grow in polluted waters. BT & BS bacteria are safe for animals and environment and cause no health risk to humans. However, Mosquitoes can become resistant to bacterial control agents. Cost of application is high considering the size of our country.	[14, 26]
Genetically modified mosquitoes	*Aedes aegypti, Anopheles stephensi*	Target a single species of mosquito. Not economically viable for our country. Also possess hazard to environment and failure risk.	[26]
Chemical control (Larvicide,	All mosquito species. All stages.	Significant hazard to already polluted environment of our country. Toxic to all forms of life. Cost of application is high.	[29, 30, 31]

Pupaecide, Adulticides)			
Insect Growth Regulators (IGR's)	Adult, eggs, larval and pupal stages of *Aedes aegypti, Anopheles stephensi, Culex quinquefasciatus*	IGR's themselves having a good margin of safety to invertebrates, fish, birds, and other wildlife. They are relatively safe to man and domestic animals. However, these are very slow acting and are often combined with chemical control agents such as pyrethrins. Very costly with potential environmental hazards with respect to our country.	[39]
DRDO developed technologies		The technologies developed by DRDO give emphasis on both public and individual mosquito control. Although developed specifically for army personnel and to a certain extent to the individuals living in border areas, there is needed to incorporate these technologies into the national vector control programs so that their benefits shall reach to the common people.	[38, 40, 41, 42]

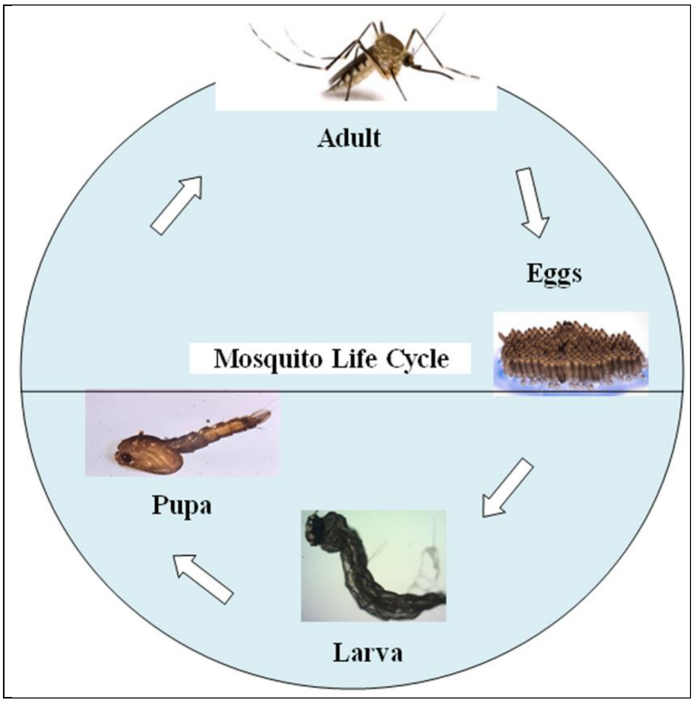

Fig 1: Mosquito life cycle.

4. Conclusions

India carries a heavy load of mosquito-borne diseases as a result of the climatic circumstances, growing urbanisation, infrastructure building activities, and mosquitoes' capacity to adapt to extreme climatic conditions. To get rid of mosquito menace, over the years a number of mosquito control strategies have been developed worldwide. These mainly include physical, chemical and biological controlled strategies. With rapid development in science, these control strategies are continuously improved with respect to their efficacy. However, not all the advancements are implementable in India to counter the mosquito menace. The main hurdle is cost of implementation and technology development. Although we are the third largest economy in the world but still, we are not able to absorb huge cost of implementing advanced controlled strategies. Not only the huge cost, we have also look into the hazards posed by the control strategies to environment as a whole and living being in particular. From the review of all the controlled strategies, it was observed that one of the most effective mosquito control strategies is physical control. This strategy can be implemented at both public and individual level without polluting the environment. At public level, this can be implemented through reduction in mosquito breeding sites, whereas, at individual level, this can be practiced through using mosquito traps, electrocuters etc. After physical control, another effective control strategy is the use of larvivorous fish. This strategy is particularly useful for the areas where there is lodgment of water such as ponds, paddy fields, large water tanks etc. Comparatively cheaper than other management methods are the introduction of larval fish. However, this strategy may sometime pose danger to region specific aquatic fauna. Mosquito control through bacteria is also a useful strategy but cost of implementation is very high. Moreover, mosquitoes may also become resistant to bacterial control agents. Recently, genetically modified mosquitoes have been tried as a tool to control the mosquito menace. However, these mosquitoes target a single species and are extremely expensive to develop. Further, these may pose unknown danger to the environment and failure of this approach has also been reported in some parts of the world. Chemical control of mosquitoes must be employed as last resort because of significant hazards to the environment and living beings. One more thing, we would like to suggest that government should run health education programme at school level so that useful information regarding control of mosquitoes especially by physical means is effectively transferred to the kids. As the school going children are very sensitive and curious, it is our belief that this information will be deep seated in their conscience and will work far better than distributing pamphlets or indiscriminately writing on the walls.

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