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REVIEW ARTICLE

Anthropocene- An Era with Evil Six Threats Changing the Fate of Biodiversity: Emerging and Re-emerging Aboviruses Calls for Holistic Approach

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Abstract

The Anthropocene era is characterized by the ever-increasing anthropogenic activities which serve as a driver of the evil six threats (climate change, overexploitation of earth natural resources, land-use change, invasive alien species, pollution, and nutrient loading) to biodiversity, these, in turn, contributes to the alarming emergence and re-emergence of arboviral diseases. The major concern of this on human population is the increased morbidity and mortality rate, and as evidently reported by the World Health Organization in their report entitled "global brief on vector-borne diseases," vector-borne diseases including arboviruses accounts for ~17% of the global burden of communicable diseases and > 700,000 deaths per annum across the globe. Hence, an impending global health threat that requires attention. This paper, therefore, explicates the positive correlation of the evil six threats to biodiversity with the emerging and re-emerging arboviruses and finally recommends the adoption of a One Health approach as a panacea.

Keywords

Anthropocene, Emerging and re-emerging arboviruses, Evil six threats, Biodiversity, One Health approach

Introduction

Emerging and re-emerging arthropod-borne viruses i.e. arboviruses include West Nile virus, Chikungunya virus, Dengue, and Zika virus. Most of these viruses belonging to four major families (*Togaviridae, Flaviviridae, Bunyaviridae,* and *Reoviridae*) are transmitted to humans and animals through the two important species of *Aedes* mosquitoes vectors (*Ae. aegypti* and *Ae. albopictus*), and continue to pose a significant threat to the global public health due to rapid spread of infections [1,2]. However, this threat is on the rise in an era dubbed by a group of distinguished Geologists as Anthropocene. This era is characterized by the ever-increasing anthropogenic activities such as intensified agriculture and illegal mining which are rapidly changing the fate of biodiversity-the systems that protect all lives, through the evil six biodiversity threats including climate change, overexploitation, land-use change, invasive alien species, pollution, and nutrient loading [3,4]. These key threats to biodiversity are known to alter the geographical distribution of arthropod vectors and in turn, contribute to the spread of arboviruses across the globe, and health effects of these include high mortality and morbidity rates in the human populations [5]. The outbreaks of Dengue and Chikungunya in Gabon and the recent epidemic spread of Zika virus throughout the Latin American countries is obvious evidence that arboviruses will continue to emerge and reemerge [6]. However, to prevent and control the spread of emerging and re-emerging arthropod-borne diseases requires the adoption of a holistic approach like One Health that works with vector-host-ecosystem interface to ensure biodiversity conservation.

Climate Change and Arbovirus Diseases Transmission

Climate change as one of the key threats to biodiversity caused by anthropogenic emission of greenhouse gases contribute to the emergence of arthropod-borne

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diseases and this is evident by changes in reservoir and shift in vectors' distributions. Temporal and spatial distribution of vector-borne diseases is altered as a result of changes in climatic variation which create new habitat and ecological niche for vectors [7,8]. According to a report by the Intergovernmental Panel on Climate Change (IPCC) in 2018, the global mean temperatures are estimated to increase by 1.5 °C by 2030 to 2052 [9]. This estimated rise in temperature has the potential to increase the distribution of arthropod vectors, thus enhancing the rapid circulation and outbreaks of arboviruses-as arthropod vectors are very sensitive to temperature variability, and can affect their population size, the extrinsic incubation period (EIP), susceptibility to viruses, survival, breeding, fecundity, and competence [10]. The vector competence is a key determinant of arboviruses transmission and it is climatically (mean temperature and diurnal temperature range) modulated and can be determined genetically [11]. The *Aedes* mosquitoes including other widespread vectors like *Culex* mosquitoes, sandflies, and *Culicoides* are ectothermic and cannot on their own regulate body temperature, hence depend on ambient temperatures for physiological development and other biochemical processes [12]. Changes in ambient temperature will directly affect *Aedes* mosquitoes by favoring their biting behavior, fecundity, competence, and increase their frequency of viremic blood-meal [13]. This, in turn, contributes to the likelihood of vector-borne disease transmission [12]. Increased ambient temperature stimulates vector competence, increases frequency for a viremic blood meal, and viral replication rate is high [14,15]. Contrarily, these activities have also been reported to occur at lower temperatures in some *Aedes* mosquitoes' populations transmitting Dengue fever and Chikungunya virus [15]. This evidence establishes the fact that the effect of ambient temperature on arthropod vectors is, therefore, not a one-direction impact and thus requires more studies. In their study in Singapore, Struchiner and colleagues revealed that the spread of Dengue fever over the past 40 years was due to an increase in temperature favoring the competence of *Ae aegypti* and *Ae albopictus*-the vectors of the disease [16]. Similarly, an increased temperature has been associated with the incidence of Chikungunya virus during its first outbreaks in Italy [17]. Heavy rainfall from climate change also favors the fecundity of *Aedes* mosquitoes as eggs are deposited during this period and hatched in favorable conditions, thus, increases the spread of arboviral diseases such as West Nile Virus [18]. Additionally, hydrometeorological events like intense drought and flooding linked with the extreme El Niño and La Niña events [19] have also contributed to the spread of arboviral diseases. In a modeling study by Lowe and colleagues, these extreme events have been linked with the incidence of Dengue fever in Barbados [20].

Overexploitation of Natural Resources and Arbovirus Diseases Transmission

Overexploitation of the earth's natural resources and urban habitats in response to the ever-increasing-population-growth demands threatens biodiversity [17]. The rate at which natural resources are exploited through illegal mining, logging, and monoculture practices is quite alarming, and the effect of this includes deforestation which is associated with emerging and re-emerging diseases [17]. The loss of biodiversity as a result of anthropogenic changes like deforestation has contributed to increased contact between human and arthropod vectors and in turn, facilitates the spread of arthropod-borne zoonotic diseases [21]. Biodiversity plays an important role in the moderation of vector-borne disease risk through the mechanism termed "dilution effect" [22,23]. The dilution effect entails a lower susceptibility of vectors to infection by pathogens in higher diversity due to the availability of incompetent reservoir hosts to dilute the disease transmission rates between vectors and the competent host [21,23]. In their study, Ezenwa and colleagues reported that the infection rates of mosquitoes with West Nile Virus are lower with species richness of avian birds [22]. Also, a lower incidence of West Nile Virus has been reported in some administrative regions of the United States with higher diversity of avian species-the viral host [24]. However, deforestation establishes a negative relationship with the "dilution effect" as it tends to alter the distribution of sylvatic mosquitoes vectors which can migrate and disperse into new ecological niche most especially the human population, with urbanization and population expansion facilitating their contact with the human hosts, thus exposing the population to important/novel vectors of human pathogens [25]. The spread of Kyasanur forest disease in South India has been associated with deforestation [26].

Land-Use Change and Arbovirus Diseases Transmission

Land-use change is another important threat to biodiversity and its relationship with the emerging and re-emerging arboviruses has been established in several studies [27,28]. Increased change in land-use for agricultural activities such as livestock and monoculture practices result in the disruption of biodiversity which can lead to loss of *Aedes* mosquito vectors habitat, the hosts, and the pathogens. This, therefore, affects the distribution, abundance, vectors' host-seeking behaviors, oviposition, the dynamics of hosts, vectors migrating to new habitat niches and favorable blood-breeding sites, and spillover of arboviruses [28,29]. Several studies allude to the fact that the emergence and re-emergence of arboviruses are associated with land-use change. As suggested by Ali and colleagues, changes in anthropogenic land-use are one of the main drivers of the emergence and re-emergence of the Zika virus across the

Americas [30]. Similarly, in another study by Vanwambeke and colleagues, Dengue risk for *Ae. albopictus* in Hawaii has been associated with land-use change [31]. Weinstein and colleagues also established the positive correlation of land-use change with outbreaks of Zika virus in Colombia [32].

Invasive Alien Species and Arbovirus Diseases Transmission

According to the National Invasive Species Council (NISC), invasive species are species (plants, microorganisms, birds) whose migrations to a new habitat have the likelihood of causing health, economic, and environmental harm to human, animal, and plant health [33]. The introduction of invasive alien species due to international sea and air travel is the second most important threat to biodiversity following habitat destruction. *Aedes aegypti* and *Aedes albopictus* are significantly recognized invasive mosquito species that contribute to the widespread of arboviruses like Dengue fever, West Nile virus, yellow fever, Chikungunya virus, and other pathogens of public health importance [34]. These invasive alien species are always difficult to control due to high rates of reproduction and increased ability to thrive in different climatic regions and habitats, their adaptation to synanthropic locations where they derive an abundant source of hosts' blood-meal, and easy location of breeding sites (man-made larval habitats such as tires and artificial water containers) for larval survival [35,36]. The outbreaks of Chikungunya virus in the Indian Ocean and South Asia dated to 2005 have been associated with a high density of *Ae. Albopictus* [37]. Similarly, the outbreaks of Dengue virus in Gabon and Hawaii in 2007 and 2001-2002, respectively, have been linked with increased density of *Ae. Albopictus* [38,39].

Environmental Pollution and Arbovirus Diseases Transmission

Environmental pollution is another threat to biodiversity which in turn contributes to the spread of infectious diseases, particularly arboviruses such as Zika virus, Dengue fever, and yellow fever. Pollution of water bodies and ditches due to anthropogenic activities of man such as mining and oil exploration give rise to abundance breeding sites for the Asian tiger mosquito (*Ae. albopictus*) and *Ae. Aegypti* [40]. Improper wastes disposal and inadequate environmental sanitation practices are associated with the arbovirus epidemics as there is a high incidence of mosquito infestation in densely populated areas, this is because vectors tend to find suitable hosts easily. It is also important to stress that vector proliferation increases with migration to urban areas with poor sanitation practices. High frequency of rainfall also leads to the accumulation of water in used tires and containers-that can provide the breeding sites for *Aedes* mosquitoes. This contributes to the rapid invasion of the *Aedes* mosquitoes and increases their frequency for a blood meal, thus leading to arbovirus epidemics in the human population [41]. Several studies linking the emergence of arboviruses with the unsanitary environment have been documented. Zika virus, yellow fever, Dengue, and Chikungunya epidemics in west Brazil since the beginning of the twentieth century is associated with poor sanitary condition and increased wastes generation which facilitated the proliferation of *Aedes* mosquitoes, particularly *Ae aegypti* [42].

Nutrient Loading and Arbovirus Disease Transmission

Asides from industrial and chemical sectors, nutrient loading from the agricultural sector is a critical threat to biodiversity including the terrestrial and aquatic environment [4]. Nutrients use in agriculture play an important role in the growing cycle-a major source of environmental pollution from nutrient [43]. It has been estimated that ~70% of nitrogen and about 50% of phosphorus in effluent discharges entering the water body are from the agricultural sector, thus, leading to eutrophication, soil acidification, loss of biodiversity, and changes in species composition [44-47]. The intensification of agricultural activities in response to population-increase demand for farm produce has led to increased fertilizer use in farmland to stimulate the growth of plants and facilitate yield, this, in turn, leads to environmental pollution by nutrient [43]. An increase in nutrient availability in the environment can affect the arthropod vector, the host, and the pathogen through an anthropogenic activity like land-use change-known to alter vectors habitat and the amount of food available for the development and survival of immature (larvae and pupae) and adult mosquito (imago) [48,49]. Consequently, nutrient enrichment facilitates planktonic algal growth and other microbes that tend to serve as nutrient sources for immature mosquitoes which increase their developmental stage, period of emergence, and abundance [50]. Presence of high nutrient in the environment enhances the breeding of adult mosquitoes, promote the development of immature mosquitoes, thus, facilitating the spread of arthropod-borne diseases [49-51]. In their study, Lawler and Dritz established a positive relationship between increased reproduction of *Culex restuans* (an important vector of West Nile virus) and nutrient enrichment with rice straw in California rice fields [48]. Reiskind and colleagues also reported a high rate of larval survival and emerging adults in highly enriched nutrient samples than in control ones [52].

A Choice between the Holistic Approaches: One Health as a Panacea to Arboviral Diseases

Over the past decades, several holistic approaches have been established to safeguard human health against public health threats. However, the three most influential approaches to date are One Health, EcoHealth, and Planetary Health-the most recent of all [53]. Since the

emergence and re-emergence of arboviruses are linked with the evil six threats to biodiversity, adopting a One Health approach that seeks to reduce and prevent the health threats occurring at the interface of humans, animals, and their shared environment could be the best mechanism to cope with arthropod-borne diseases. As defined by the United States Centre for Diseases Control and Prevention, One Health is a multidisciplinary and intersectoral approach involving expertise at the international, national and local level working together to understand the existing connections between humans, animals, and their shared environment to optimize their health [54]. The history of this approach dates back to 1800 when scientists recognized an intimate relationship in the processing of diseases between humans and animals [55]. The rapid emergence and re-emergence of arboviruses and the arms race between biodiversity conservation and the evil six threats to biodiversity are the most challenging issues across the globe. To protect the biodiversity from the evil six threats and to cope with emerging and re-emerging arboviruses, the global health community can adopt the One Health approach by taking the following steps: First, researchers from multiple disciplines including ecologists, public health scientists, epidemiologists, metagenomics and modeling experts, and microbiologists should work together under the platform of One Health to monitor the evil six threats to biodiversity that are contributing to the spread of arboviruses as well as identify hotspots for sampling. Second, there is a need for an integrated entomological surveillance system that should be compatible with all relevant countries [56]. This is very essential because pathogens, vectors, and hosts do not recognize borders [57]. Third, an international framework convention in One Health conceptual aimed at tackling the spread of arboviruses should be implemented. Fourth, intersectoral and multisectoral engagement in One Health platform should be coordinated and supported by the government in the fight against the emerging and re-emerging arboviruses. This will enhance the early preparedness, prevention, and prompt response to arbovirus epidemics. Fifth, the local communities including schools and religious organizations should be sensitized on identifying the risk factors of arboviruses as well as involve them in the fight against arboviruses. This is pertinent to enhancing the effectiveness of the One Health approach.

Conclusion

The evil six threats to biodiversity have a direct relationship with emerging and re-emerging arboviral diseases which continues to pose a significant threat to human health and well-being across the globe. Addressing these diverse threats requires the immediate adoption of the One Health approach that involves interdisciplinary and multisectoral prevention and response to the spread of arboviruses. Research priorities amongst researchers from relevant disciplines should therefore focus on integrated surveillance systems, factors contributing to the geographical distribution of arthropod vectors and those favoring the transmission of arboviruses. The implementation of this approach should be supported by the government and relevant stakeholders and this can help in mitigating the effect of emerging and re-emerging arboviruses.

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