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Vector Borne Disease Ecology and Environment: Remote Sensing and GIS for Control and Management: A Systematic Review

Palaniyandi Masimalai [a*]

[a] *Department of Geography and Disaster Management, Tripura University (A Central University), Suryamaninagar, 799 022, Agartala, Tripura (W), 799 022, India.*

Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

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Review Article

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ABSTRACT

The prevalence of vector borne disease epidemics are influenced by the thickness of the vectors persistent to climate, landscape, and environment. Historically evidenced of triggering epidemics in both vertical magnitude and horizontal spread (spatial diffusion) of increasing vector borne diseases, such as; malaria, dengue, chikungunya, Japanese encephalitis, filariasis, leishmaniases, scrub typhus, Kyasanur forest disease (KFD), West Nile virus, Lyme disease, Zika virus, and Rift valley fever in the tropical and subtropical regions, particularly, in the third world countries for the past several decades. The geographical analysis of each one VBD epidemics has a unique vector ecology and environment. The prevalence of epidemic distribution patterns and seasonal variations, and associated vector ecology were analyzed throughout the world for the past periods, in order to

**Corresponding author: E-mail: palaniyandimasimalai@tripurauniv.ac.in;*

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assess the probability of potential risk and delineate the hotspot regions susceptible to the VBD outbreaks in the country, using Remote Sensing and GIS mapping analysis. It offers a quick and efficient approach to mapping of land uses/land cover patterns and its changes over space and time, and the information on these changes linking with vector profusion and disease ecology. Vector-borne disease epidemics across the country have been evidently associated with climate factors, landscape changes, potential breeding sources; such as, water bodies, rivers, streams, and mega water resource irrigation projects, dams / reservoirs, water pools, lakes, urban agglomerations, Urban sprawl, urban dynamics, industrial developments and growths, floating population, urban migration, land use / land cover changes, wet irrigation agriculture practices, seasonal migrations on occupation, cargo shipping movements, trade and commerce, etc., and have been acted upon changing the aboriginal territories by extent of epidemic scenarios into the non-endemic regions. The integrated Earth Observation Resource Satellite data integrated with GIS has effectiveness upon proved to disease mapping, ecological niche modeling, risk assessment, spatial prediction, and offering answers to both the public health programmers and research scientists concerned on vector fecundity, and vector borne disease ecology, and thus, the geographical, ecological and environmental determinants of its range is considered to be essential for sustainable public health planning. Accordingly, prevention measures and appropriate control strategy may possibly be applied during the sporadic outbreaks situations in the new epidemic regions as well in the hot spot endemic regions regularly, so as to control the erratic transmission and prevent acceleration of epidemics early in advance successfully.

Keywords: Remote Sensing and GIS; mapping disease prevalence; vector borne disease ecology; malaria; dengue; chikungunya; Japanese encephalitis; leishmaniasis; filariasis; scrub typhus; Kyasanur Forest Disease (KFD); Zika virus, tropical infectious diseases.

1. INTRODUCTION

A disease caused by virus, bacteria, pathogens and parasites in the human body that are transmitted through bites of infected arthropod insects or animals (mosquitoes, fleas, mites, ticks, rats, snails, sand flies, and dogs) are called vector-borne diseases. The prevalence of vector-borne diseases is geographically distributed in 142 countries across the world [1-3], has much attention on the illness and disability, casualty, and economic losses to the individual patient as well to the nation. In India, the geographical distribution of both vertical and horizontal epidemic pattern of dengue, chikungunya, Japanese encephalitis, malaria, filariasis, leishmaniases, filariasis, scrub typhus, Kyasanur forest disease (KFD), and Zika virus epidemics are contributed 16% of the illness, and has become most important challenging health issues in the recent decades [1-3]. “Ecological and environmental transition caused by human activities has a direct result in increasing the number of breeding sites [4]. Construction of road networks, human settlement, commercial buildings, and poor maintenance of these canals and water outlet channels often impede drainage of runoff from rainfall. Blocked drainages or ditches along roadsides must be desilted or removed, so as to avoid the perfect places of man made construction activities fueled for flood water mosquitoes” [4]. “Domestic waste discarded containers in the peripheral areas around the house, collects rainwater, and allows dengue, chikungunya, and zika virus vector mosquitoes to breed in the surrounding areas of human dwellings, limits of their habitation [5-7]. The potential vector breeding sites of vector mosquitoes are varied in respect to space and time. The malaria vector species require widespread vegetation cover, preferring swamps and other permanent water bodies with organic matter” [8-10]. “Aedes species, dengue, chikungunya, zika virus vector mosquitoes breed in discarded containers, plastic cans, tins, discarded tires, mud pots, stone grinder, potted plants, coconut shells, drums, cement tanks, tree holes, crabholes, fridges and AC machines water discharge containers” [7]. “Anopheles species, malaria vector mosquitoes breeding sites are found anywhere in fresh water collects [8-11], and as well JE vector mosquitoes i.e. Culline mosquitoes family groups, mainly Cx. vishnui species (Cx. tritaeniorhynchus, Cx.epidesmus, Cx.pseudo vishnui, Cx. whitmorei, Cx.leucocephala, Cx.gelidus) breeds in wet irrigation paddy cultivation fields” [9]. “Filariasis is transmitted by all the three groups; Anopheles, Aedes, and Culex quinquefasciatus. Culex mosquitoes breed in turbid water (ditches, septic tank, cesspits, trainages, and Mansonia breeds in stagnated small pools with certain aquatic plants, example:floating type like Pistia stratiotes and water hyacinth vegetation)"[12]. Leishmaniasis vectors; sand flies prefer breeding grounds mostly rich moist soils, contaminated soil of animal shelters, rodent burrows, buttress roots of trees, termite hills, caves and among rocks, and the earthen floor of human habitations, as breeding sites [13-16]. "KFD and Scrup typus vector ticks and mites are breeding in the unique ground surface of the deciduous forest land covered with wet moisture soils, and around the earthen floor of human habitations" [17-19]. "Permanent or perennial natural bodies of water, such as swamps, serve as unique breeding grounds for Anopheles species mosquitoes"[20]. "A direct correlation was established between the availability of vector breeding habitats around the human inhabitants and the frequency of mosquitoes feed on humans20. Drainage, irrigation, pest control, deforestation, afforestation, pollution, and destruction of cities create changes in the habitat which eventually and inescapably will bring about challenges to human adaptation, and hence changes in the scenarios of the diseases" [4,7,20,30,47]. Several sites of the man made ecological changes transformed into new epidemic zones, and became endemic zones due to the concomitant increase of huge migration towards these regions forced by the occupation purpose [21]. The increase of possible breeding sites are extensive, and describing a few more of them will help to illustrate the difficulty in finding a solution to control of VBD epidemics through intervention measures and control strategies.

Remote sensing and Geographical Information Systems (GIS) is the chiefly significant scientific methods have been used to mapping the environmental epidemiological determinants for better understanding of the spatial variation of the vector ecology, vector biodiversity, vector profusion, and the active infectivity of vector borne diseases [22-26]. Multispectral (MSS), and Synthetic Aperture Radar (SAR), and Microwave Remote Sensing data have been used to mapping the changes in ecological settings [22-25]. "Mapping of disease ecology and environmental aspects of vector borne diseases provide the fundamental means to stratification of the susceptible regions under risk of VBD epidemics" [22-26], and the bio-geo environmental determinants provide the key elements to assess the community vulnerable at the risk of new, emerging, re-emerging vector borne infectious diseases across nation in both the endemic and non-endemic regions [27]. "Remote sensing and GIS offers a quick and efficient approach to mapping of land uses / land cover categories and its changes over space and time, the information on changes in resource classes, direction, scale, and pattern of land uses/land cover resource classes for linking the geographical distribution and seasonal variation of vectors form a basis for choose a comprehensive vector control strategy, and management of the grumbling situation, and as a result, and lead a step for disease control moving towards the future planning for sustainable health" [27].

2. VECTOR BORNE DISEASE ECOLOGY

"All mosquitoes require water for breeding, though it can be hygienic or turbid water, sun-drenched or in the shade, running or stagnant, warm or cold, saline or clean, acidic or alkaline or polluted. Anophelines genus mosquitoes prefer clear water, Aedes species mosquitoes breed in discarded containers, Mansonia breed in small water pools, and Culex visnuvi mosquitoes breed in the rice fields, but Culex quiqufaitus thrive in dirty water. At certain hours mosquitoes seek shelter, some prefer to dwell indoors, others outdoors, some cruise high under the canopy of the forest, and others low above the ground. Rainfall and temperature, as well as the topography of the soil, combine to create situations in which mosquitoes and other arthropod vectors either multiply or reduce or nil breeding. Vector fecundity is high in the suitability of biological, geographical, and ecological variables. Man-made changes in certain cities in the tropical belt have definitely resulted in the transformation of the average and extremes of temperature, humidity, and precipitation in the same areas [4]. The phenomenon is easily observable in a metropolis like Delhi, Madurai, Chennai, Trivandrum, Puducherry, Goa, etc., where the temperature has risen in the past several decades due to the tall structured raised buildings that impede the cooling breezes from the sea and because of heat reflected from extended asphalt sheet surfaces. Environmental factors influence the parasites through the physiology of the mosquito vector and its survival rather than through influence on the parasite itself" [28-30]. "The relative humidity of the environment influences the survival of the mosquito to a great extent and has a definite effect on the development of parasites inside the vector mosquito's body "[30].

"Disease ecology must be evidently understood on the site specific and region basis. The immediate environment provides stimuli with which living things have to cope in order to survive and to which they must provide a response" [30]. "The response, as one can evaluate, depends upon the amount of stimulus in relation to the genetic makeup of the host and upon the acuity of the physician's ability to detect. The disease pattern is also governed by the environmental stimulus, vectors, and host in the construction of mores, habits, and these techniques are termed as culture. Cultural traits either bring stimulus or host together, creating the chance for disease occurrence, or keep them separate, and thus, better understanding of disease ecology gives way to preventing the disease" [31]. "All three factors are intimately related to the environment, and the transformation of the environment will automatically bring about a change in the mutual relationship of these closely-knit complexes. Environmental stimuli are conveniently classified as physical, biological, cultural, and heritable different" [31]. "Mapping of review of disease ecology risk factors provides information to understanding the stimulus, disease host, and culture that the science of the disease ecology on an area basis" [31], and scope of the subject of global epidemiology [12-14, 32-36].

3. CLIMATIC AND VECTORS DISTRIBUTION

Changes in climate (temperature, humidity, and precipitation) [37-40], altitude, landscape, population density, people migration, human habitations nearby vector breeding habitats, and deforestation are acted as the ecological risk factors that have played essential parts in the occurrences of epidemics and transmission of VBD7, [10, 14, 30]. "Temperature, humidity, and precipitation have a direct influence on the survival and longevity of the mosquito vectors [37-40], and can thrive at an optimal level as a result of ecological and environmental adaptation. The spatial diffusion of VBD involves that the ecological variables must have suitable conditions for the survival and longevity of both the mosquito and the parasite. Mosquito density is associated with the breeding habitats around the human inhabitant, and thus, VBD transmission epidemics are directly correlated with mosquito density" [30]. For example; "Temperatures from approximately 21°-32°C and a relative humidity of minimum 60 % are most conducive for maintenance of malaria transmission [41]. Malaria parasite development requires minimum 7 days, and therefore, *Anophelines* female mosquitoes must live 18-21 days, and the minimum length of parasite development is directly dependent on temperature and humidity in the mosquito habitats in the endemic regions so as to develop *Plasmodium* parasites in the mosquito's body, i.e., vector mosquito longevity directly affects malaria transmission, human infection, and epidemics" [41]. The conditions of stress thus created resulted in a susceptibility to the agents that had not existed before. Further, "the physical elements of climate risk factors have influenced the human physical conditions as well as the disease causing agents, vectors, intermediate hosts, and reservoirs of pathogens that bring human infectious / transmissible diseases. The whole field of climatically- induced mutations in agents, vectors, and intermediate hosts that could modify virulence, susceptibility, and immunity is practically un-explored and will be alluded to below biological stimulus" [10,20,23,37,38].

4. ALTITUDE, DEFORESTATION, AND VECTOR DISTRIBUTION

Altitude is significant in determining the distribution of malaria and its seasonal impact on many regions of the world, for example, the landscape situated in the altitude >1000-1500 M are mostly considered as safe from malaria infection in Sub-Saharan Africa [42,43]. However, it has cautioned that the continuous process of global warming and continuing climate change, these figures may be changed, and extend the spread of mosquitoes well above these limits of altitudes range due to ambient temperatures rise. Deforestation activities are the most disrupting man made process affecting mosquito populations. On the other hand, deforested areas are typically converted into grazing pastures, agricultural plots, and human settlements. These changes in ecological setup allows for the propagation of mosquitoes around the human inhabitants[1]. Massive breeding habitats for *An. bellator* and *An. homunculus*, turn to increasing the opportunity for effective transmission of *P. malaria* in rural areas in Trinidad, due to extensive deforestation during the 1940's, and replaced with imported trees *Erythrina micropteryx* (*Immortelle*) from Peru (South America) to shade the cocoa trees, and as a result, *Bromeliads* (*epiphytes*) began to grow in the region, provided the water-collecting bromeliads which are the preferred breeding grounds for malaria vectors [44]. “The prevalence of malaria epidemics was drastically reduced by spraying dilute solutions of copper sulfate in the *bromeliads*. Conveniently, control measures have been taken to prevent the epidemics [44]. The typical evidence of even insignificant changes in the ecological conditions, like these deforestation and plantations has been replaced with imported plants produced a constructive environment for malaria transmission where it was not existed earlier than” [44].

5. BIOLOGICAL AND ENVIRONMENTAL RISK FACTORS

“The environmental conditions are challenging human survival, comprising all the living organisms which have selected to inhabit the micro climates and microclimates suited for living in the surrounding [4]. An important aspect of the coexistence agreement developed by these living things, which the physician and even the public health officer often forgets, is that these living things, like men, live in societies. It is similar to thinking of a society as a pattern of mutual tolerance that occurs temporarily among living things when the dynamism of reciprocal exclusion has been exhausted. The idea stressed in these words is that a social structure is essentially temporary, based on mutual tolerance, which implies dominance and submission. The moment anything happens to disturb the equilibrium of this compromise, the pattern is upset and new dominants come to the top with unpredictable results. The reason for all these, of course, is that whatever size they are, living things always compete for food and shelter and organize themselves temporarily on a pattern of mutual strength and power. The change in environmental conditions has directly influenced the mosquito’s breeding habitats” [30,31], by a natural process or through human intervention, rearranges the ecological landscape in which these vectors breed [37-40]. All the mosquitoes inhabit a particular ecological condition, and are genetically determined [7,10,14,30]. It is profitable for the medical ecologist and medical public health entomologist to study the occurrence of transmissible diseases throughout the world to remember that, in all likelihood, vectors, bacteria, virus, pathogens, parasites, are all living in the living human environment.

“In a paddy field sown with *gambusia*, the mosquito *Anopheles jeyporiensis candidiensis* would have a difficult time surviving and so would the parasite *P. vivax* for lack of adult mosquito habitat in which to spend its sexual life” [8,11,41]. “It has been shown that it is difficult to have the yellow fever virus multiply in an *Aedes aegypti* previously fed on dengue virus [45]. Could it be that these two viruses cannot belong to the same social structure because of some competition that is not yet understood?” [45] “The social structures of living things are closely dependent upon the geographic risk factors and the food availability discussed above, which is why one can find these societies closely integrated and almost identified with the map of the geographical boundary in which they occur. Hence, a good understanding of the map of disease must be based on an in depth study of the relationship between physical geo-environmental factors (climate, landscape, and environment) and biological factors (cells, tissues, and organs of the host) in different space and seasons [50]. Health and disease, in the final analysis, should be conceived solely as a function of the ability of a living thing to adjust to the environment in which it lives” [27].

6. MAPPING DISEASE ECOLOGY

“Sometimes these adjustments are orderly and unconscious; sometimes they shake the tissues, disturb the functions, and upset the whole organism beyond the range of unconscious integration and the individual is made aware of the change. Until adjustment is eventually made, this change can be called disease. If adjustment is not made, death occurs. If it is made, a scar is left which will play its role in the future behavior of the tissues and in future adjustments to new stresses. A study of the changing map of disease implies first a study of all the stimuli that have been discussed and then a study of the factors that govern responses from the host. These are all important. Given many aggressive stimuli, the living hosts respond according to their respective genius in a way that modifies the map of disease. The relationship between genetics and the development of human illness has been closely linked with the environment. The present and future genotype of a population is dependent upon the presence of environmental stimuli which cause mutations and on the pressures which force living things into migrations [4]. Mutagenic factors are little known; however, heat, chemicals, radiation, and probably others are specific to environmental niches: the way these factors combine determines the microclimates or microclimates for all living things ” [4]. “These climates exert their influence on the genes of plants and animals alike, causing mutations that upset the social patterns referred to above, causing dominants to lose their dominance and submissive elements to acquire dominance" [20]. Thus disease patterns are genetically linked with geographic pressures. "In the same way, the environment in which man lives pressures his genotype, and brings about new shapes and new phenotypes that may be useful or detrimental to the continuation of his living in that same place. If a man has lived for a certain time in a certain environment, he has been bitten and hurt; he has suffered emotions that are specific to that place. All these stimuli have left scars, the sum of which form his personality and govern his future response to future stimuli. Some of these scars are beneficial, such as immunities and education; some are detrimental, such as allergies and neuroses; and it is the total of these scars that governs the disease pattern by governing responses to the stimuli present in the environment. GIS map illustrates the susceptibilities and immunities of the fussiness of the vector borne infectious diseases in a specific region" [27, 46].

7. SOCIO-ECONOMIC AND CULTURAL DETERMINANTS

"The VBDs ecology and environment forces that socio-economic, and cultural determinants ambitious are acted as the interceded risk factors; the prevalence of spatial patterns are with various human groups that grow in the infinite variety of physical and biological environments" [4,7,30]. To the global epidemiologist, culture is the sum totals of the concepts and techniques that individuals or populations devise and use in order to survive in a specific environment [4, 7, 30]. Of course, not all cultural traits are survival-worthy. It is quite possible that many cultural traits will lead the group to its destruction rather than to its survival. A case probably could be made to show that cultural traits originally developed because they were thought to promote survival or because of that they did promote survival when they were adopted, but that they often have ceased to do so under changing circumstances. People do not give up their culture easily. They often like to feel the protection of their ancestors around them and they often would rather die doing something that has always been done than survive by not doing it or trying something that has not been tried before.

"It seems that a transformation of the environment will bring about changes that will modify the adaptation of man to his milieu. These environmental changes occur as follows: alluviums fill up estuaries; isolated villages are replaced by large cities; vast populations multiply and create crowded situations; people migrate; genes segregate; and new genotypes are created which result in new responses to the environmental stimuli. Explore to understanding the new, emerging, re-emerging pathogens, virus, or bacteria in associated with geographical stimuli for a disease in specific sites, the changes in social structures of agents and vectors, and changes in the scenarios of immunities and susceptibilities of the community create new links between agents and hosts or protective shields between them are highly significant" [47,56].

8. ECOLOGICAL ZONES AND VECTORS

"Construction of water resource projects are leading to shifts in vector mosquito populations. Reservoirs, dams, lakes, and irrigation canals and other related water projects have been constructed, and operated to meet human needs such as drinking water, energy generation, and agricultural production, on the other hand, are strongly fueling for the fecundity of vector mosquitoes, and new and emerging parasitic diseases" [9,11,42]. "Water resource projects are essentially inevitable for the sustainable agriculture production, economic and social development, however, it has been brought unwanted environmental changes leads to introduction of new pathogens, parasites, bacteria, virus, and vectors, and consequence of a few negative effect on human as well animal health issues including malaria, Schistosomiasis (bilharziasis), leishmaniasis, Japanese encephalitis (JE), dysentery, cholera, and river blindness" [9,42]. "The national level water resource projects bring the multiplier effect on economic growth, agriculture industries, and allied developmental activities change the socio-economic status by alleviating poverty significantly, and significantly contribute to the enhancement of health care services to ascertain sustainable health. During the construction of mega water resource projects, dams and canals, excavation and massive population relocation has occurred, and the artificial excavation pits provide ideal grounds for temporary vector breeding habitats for mosquitoes, and introduction of new strains of malaria parasites has brought by the migrant people who are sifted for construction of reservoirs dams, and hence, malaria epidemic transmission occurs hastily at the new areas" [9,11,42].

9. MALARIAL PARASITES AND DISEASE ECOLOGY

"Malaria parasite was discovered during 1897-1898 in India, by a British Scholar Ronald Ross, who established that female *Culicine* mosquitoes are the culprits transmitting the parasite is a protozoan belonging to the genus of *Plasmodium. P. falciparum* is widely distributed in the tropical regions across the world, and is alone is the most dangerous parasite causing heavy morbidity. *P. vivax* is spatially distributed in the sub-tropical countries, and *P. ovale and P. vivax* geographically exist in West Africa" [1,2,42,43]. "At present, more than 400 malaria parasite (*Plasmodium spp*.) species existing in the world [1,2], of which, many parasites infect animals, and among them only four *Plasmodium* parasites, such as; *Plasmodium falciparum, Plasmodium vivax, Plasmodium ovale,* and *Plasmodium malariae* are routinely caused infection in human, is transmitted by the bite of an infected female *Anopheles* species night-biting vector mosquitoes, most commonly bite between dusk and dawn" [1, 2]. The ecological changes, landscape alterations, environmental transitions, land use, / land cover dynamics, climate changes are fueling to facilitate the spatial diffusion of the parasite infection into the adjunct new areas from the epicenter of the malaria prevalent sites [4,9,11,38,42]. It is difficult to understand the complex of malaria risk factors; however, a study of disease ecology reveals the complexity of the ecological differences in the malaria endemic prone areas. Gaining a better understanding of the disease ecology could be achieved by the study of four major aspects, such as; the host, the vectors, the parasites, and the ecological niche in which malaria epidemic transmission have occurred, and thus, related environmental risk factors are instigated to identify the risk zones for the purpose of controlling the epidemic transmissions.

"The survival of the mosquito is then the key to *Plasmodium* dominance and obscures the *Plasmodium* related factors which, however, combine to create the range between high and low endemic. Given this close relationship between *Plasmodium* dominance and mosquito survival, the study of environmental changes that can influence the map of *Plasmodium* through the map of mosquitoes is the most rewarding. Mosquitoes prefer breeding sources nearby human dwellings within a buffer one of 2.5 KMs mainly for human blood meal, and are fulfilled with their food, reproduction, and shelter" [41]. "The habit of watching the crops at night, to guard against thieves, staying in the forest fringe to start work on the next day, also influences the chances of being bitten, and of spreading the dominance of *P. falciparum*. The most important factor governing the development of *P. falciparum* inside the mosquito is environmental temperature" [20, 23, 38-41]. "Very high or very low temperatures prevent the establishment of mosquito infectiousness. The local temperature governs the time required for the mosquito to become infective after its blood and *plasmodia* meal. This relationship to temperature explains the predominance of P. vivax and *P. malariae* in the temperate zone and that of *P. falciparum* in the tropical belt. It may also explain the earlier occurrence of *P. vivax, and P. malariae* cases in the spring season and followed by the later manifestation of *P. falciparum* infection in summer or autumn seasons" [41]. Since temperature varies with altitude, temperature also regulates the time limits of the transmission period in mountainous regions. Winds indirectly influence rainfall, which, in turn, influences temperature and therefore affects infectiousness [20, 23, 38-41]. The malaria vector mosquitoes concerned, what are the ecological factors that favour (a) the growth and development of *P. falciparum* in the mosquito, and (b) the dominance of *P. falciparum* prone mosquitoes in the environment? Some of the factors that determine the growth and development of the parasite in the mosquito are probably inherited aboriginal *Anopheles* genus mosquitoes in nature where the region has a unique ecological setup. The mechanism of this mosquito susceptibility and parasite adaptability must have genotypic as well as environmental cases.

10. MALARIA VECTOR ECOLOGY

"The longevity of the mosquito depends, of course, on two orders of factors. Some are totally unknown because they are inherent to the genetic constitution of the mosquito. Others depend again on environmental circumstances such as temperature, humidity, winds, and light. A presence or absence of some lethal element natural or artificially added to the environment by the presence of a competing animal, insect, or human will also influence mosquito longevity. The ecology of the human host influences to a considerable degree the dominance of *P. falciparum* in an area. It affects the chances of contact between the host and the vector. If the houses are built on the ground or on pilings, infection will depend upon the flight level of the vector. If the cooking is done indoors or outdoors, the smoke will either chase the mosquitoes away or keep them inside. The presence of animals in the vicinity or at a distance would respectively increase or diminish the risk of man being bitten. *An. minimus*, a very fierce malaria vector, abounds, it's breeding enhanced by the network of mountain streams, and fly much higher than 3 meters above the ground. The wet irrigation type of agriculture practices has an effect that in the wet irrigation rice cultivation, seeds sown by broadcasting require a longer period of irrigation than do transplanted nursery shoots. This longer period of irrigation and the resulting transformation of the environment increase malaria transmission and the predominance of *P. falciparum* in the tropical climate zones"[9, 11].

"The breeding places of the effective vector *Anopheles gambiae*, almost entirely confined to parts of the coastal swamps flooded by high spring tides and characterized by the presence of *Avicennia* mangroves and wide stretches of coarse marsh grass, *Paspalum vaginatum*. Any new transformation of the environment that would make this vegetation unavailable or modify the current of the spring tides might well have an influence on the breeding of *An. gambiae melas* and hence the predominance of *P. falciparum*. The characteristics of the water and possibly of the air above the surface, especially in terms of temperature and chemical composition, govern the presence or absence of mosquito larvae. The larval habitat may become uninhabitable both because of temperature changes and chemical transformation through industrial waste and pollution. *Anopheles quadrimaculatus* has been found to disappear from certain areas where nascent industry has brought about that kind of change. It has also been found that the degree of light and shade influences the breeding of *Anopheles albi-manus*. It also influences the adult form of the vector *An. funestus*, which enters houses after midnight, especially during moonlight" [1,2]. "Since light seems to be essential to survival of these larvae, it has been recommended that trees be planted in order to control breeding. Other species (e.g., *An. darlingi*) prefer shade, but it is difficult to identify whether this factor acts upon the larva itself or upon the organic life in the medium on which the larva feeds. The movements of the waters also influence the species prevailing in an environment; modifying the dynamism of a stream either by slowing it down above a dam or accelerating it below–may favor the growth of a larval type. Yet, most *Anophelines* mosquitoes prefer still water to running water for their breeding" [9]. "Since the larva usually breathes the air from the surface, it is to be expected that access to the surface must be unhindered; hence, the surface tension modified by artificial (oil spreads) or natural (pollen, leaves) factors will also govern the dominance of certain *Anopheline* species and the plasmodium most adapted to each strain. It is not known whether, in nature, the degree of acidity directly influences the larva or the other organisms whose presence creates or negates the existence of a survival worthy environment for the species. The requirements of the adult mosquito should be added to those of the larva as factors governing *P. falciparum* pre-eminence. These requirements will play an important role in qualifying a species of mosquito as an effective or weak vector of *P. falciparum"* [4].

"The effective characteristics of malaria vectors are as follows: i) the mosquito must enter human dwellings and be domestic (example: *Anopheles minimus*), ii) The mosquito must prefer human to animal blood; in other words, it must be anthropophagic (example: *An. gambiae*), iii) the mosquito must be long-lived, since the vector must remain alive long enough to allow the sporogony (sexual phase) to take place so that the vector harbors the agent in a form transmissible to man, and iv) the mosquito must possess the constitutional characteristics (genotype) that make it a desirable host for *P*.[48]. *falciparum*, one can list the characteristics of *Anopheles* mosquitoes" [49]. "All these characteristics of the adult mosquito are dependent upon environmental conditions, most of which may undergo transformation for many causes. The characteristics of human dwellings that are attractive to the vector will vary with light, the composition, and mobility of the air inside the house, availability of resting places after the blood meal, and a multitude of home factors best known to the mosquitoes themselves. Any changes occurring in the site and characteristics of the house will influence the mosquito presence, and thus, enhance or limit the effectiveness of a species in promoting *P. falciparum*. It is interesting to note that the *Anopheles* species that can be an effective malaria vector in one area may not be in another. The dominance of *P. falciparum* in a given environment is dependent upon a number of factors: parasite-related, vector-related, and man-related"[4]. In addition, "the environmental changes are dynamic, both as a result of natural causes and man-made. Under the constant changes of the environment, from those involving the minute amount of organic matter in the water bodies (breeding habitats) that makes the life of a larva possible, to the erection of eighty-story buildings, the dominance of *P. falciparum* will change"[30]. Most of the significant factors governing these changes are unknown, and those that are not known are obviously the most intriguing. This is probably the time to focus on the fact that *P. falciparum* is not one parasite but many parasites whose various strains are gradually being identified by researchers.

11. DENGUE AND CHIKUNGUNYA AND VECTOR ECOLOGY

Dengue and chikungunya are transmitted by the *Aedes genus* mosquito vectors (*Aedes aegypti, Ae. albopictus*). Dengue has been increasing 30 - 40 % every year, especially, for the past two decades about 45% of the global population living in the 142 countries[1-3]. The Dengue virus DEN-1, DEN-2, DEN-3, DEN-4 are transmitted to humans through the bites of infected female mosquitoes [1-3]. After the dengue or chikungunya virus incubation period between 4 - 10 days, infected Aedes genus mosquitoes could be transmitting the virus for the long-term period of its life end. Infected humans are the main carriers and multiplier host of the DEN 1-4 virus and its variants, are the source of virus serving for uninfected biting female mosquitoes. Patients who are already infected with the dengue virus are the host for transmitting the infection (for 4–5 days; maximum 12 days) through the bites of *Aedes* mosquitoes, a patient with their first symptoms becoming visible or invisible asymptomatic infected individuals. *Aedes* mosquito populations flourish in the urban human dwelling environments, breeding in stagnant water that has been habitually accumulated in the manmade discarded containers, as well, tree holes, crab holes, animal's footprint, coconut shells, pineapple leafs segments, etc. *Ae. aegypti* mosquito prefers to live in urban settlements / human dwelling, and breeds mostly in man-made discarded containers [7, 30, 37,50]. *Aedes aegypti* is a daytime blood meal feeder; its peak biting periods are early in the morning and in the evening before dusk[1-3, 37, 50]. Female *Aedes* species mosquitoes bite multiple people during each feeding period. *Aedes albopictus*, acted as vector competence, and the secondary dengue vector in Asia, has spread to North America and Europe largely due to the discarded containers, used tires (a breeding habitat) and other goods (e.g. bamboo), international tourist travellers, and continental shipping cargos through the international trade and commerce[1].

The prevalence of dengue and chikungunya epidemics in India, and *Aedes* species vector density are highly influenced by precipitation intensity, number of rainy days per month, and receives almost 7 months' rainfall every year. Mostly dengue occurred in metropolitan regions across the country and in some of the rural areas in Punjab, Haryana, Karnataka, Tamil Nadu, Uttar Pradesh, and Maharashtra, wherein the factors of humidity, temperature, and rainfall became the determinants of dengue vector development. Anthropogenic interference and weather borne determinants have been creating an environment for the outbreak of epidemics across the country [50]. "In India, *Aedes aegypti* and *Aedes albopictus* are the known key vector mosquitoes responsible for the dengue and chikungunya epidemic transmission. Spatial dengue epidemic clustered are mainly associated with socio-economic, climate, natural and manmade-environment parameters and land use / land cover, however, there is no linear relationship between the climate parameters (temperature and rainfall) and sporadic dengue cases. The immature and adult mosquitoes in association with prevalence of dengue and chikungunya epidemics has no significance difference ($t = 0.950$, $p > 0.05$), the similar study was carried by the author in the Pondicherry Union Territory during 2014, and the result shows that there is no spatial differences and seasonal variation between the rural and urban environment, and therefore, need of the comprehensive vector control strategy must be focused mainly on source reduction, and beyond routine, a crucial continuous spraying must be practiced throughout the year, moving towards the control of ubiquitous dengue transmission in the endemic region. The both immature and adult *Aedes* mosquito's population fecundity was found mostly in the dense urban dwellings and clustered society of people mainly in low income and engaged in the daily wage occupations. The NDVI values of <0.0–0.2 corresponds to dense settlement areas has statistically significant with breeding habitats positives for *Aedes aegypti* and *Aedes Albopictus* vector mosquitoes, and the people of community living in the rubber plantation, and pineapple cultivation areas (midland areas altitude 50-150 meters MSL), coastal districts of plain areas (< 50 meters MSL) in the state are demarcated as susceptible to risk of dengue and chikungunya infection, dengue vector mosquitoes (*Ae. aegypti* and *Ae. albopictus*) distribution, and density is highly associated with different landscape physiographic features and altitude as well vector mosquitoes high density, moderate density and low density was attained where the areas <150 Meters, 150-300 Meters, and 300M-600 Meters respectively, and > 600meters from the MSL hilly areas has no risk in India"[50]. "*Aedes* species vector density is highly associated with the NDVI < 0.4 and < + 1 with presence of actively photosynthesizing vegetation under the cultivation of rubber plantation, and pineapple cultivation. *Aedes aegypti* both immature and adult was the only prevalent species in the water-starved clustered settlement areas during the post monsoon period, whereas, *Aedes albopictus* was densely prevalent in most of the urban as well as rural settlement areas, especially in the poor income group clustered settlements. Tamil Nadu has 34 administrative districts, out of these, 29 districts are identified for risk of dengue infections, and are geographically associated with vector mosquitoes' distribution in 30-32 districts, and is fitted over the physiographic landscape, and altitude i.e. Hilly areas, Plain region, and coastal areas, and metropolitan cities, urban agglomeration, and semi-urban regions. Hierarchy of dengue risk assessment based on the environment, climate, and socio-economic variables are reliable information for the future planning to control and manage the tough situation epidemics in both horizontal and vertical aspects. Dengue widespread in the country is perfectly match with endemic situation high in the South India (Kerala, Karnataka, Telangana, Goa, Maharashtra, and Tamil Nadu), and the risk is also extended spatially to the Eastern States and Northern States of India (West Bengal, Bihar, Uttar Pradesh, Delhi, Haryana, and Assam), and low risk in the central part of India, and the same result was obtained, using the dengue vector entomological data pertaining to the whole country"[50].

12. JAPANESE ENCEPHALITIS AND VECTOR ECOLOGY

Japanese encephalitis (JE) is an illness of the brain caused by the *flavivirus* virus transmitted by bites of infected *Culline* mosquitoes, mainly *Cx. vishnui* species (*Cx. tritaeniorhynchus, Cx. pseudo vishnui, Cx. whitmorei, Cx.epidesmus, Cx.leucocephala,* and *Cx.gelidus*) [9, 48, 51] breeds in wet irrigation cultivation fields predominantly found in the Southeast Asia48,51, and are infected through the bites of amplifying hosts like pig animals [48,51]. *flavivirus* virus transmission is found between the host animals and vector mosquitoes. Infected humans are dead ends in the life cycle of the JE virus [48,51]. Vector competencies for Cx. tritaeniorhynchus, mosquito is varied with space and season determined by independent variables of land use / land cover, climate, landscape, ecology and environment [9,48,51]. Characterize the spatial distribution and temporal dynamics of JE virus transmission highly influenced by the potential primary vector abundance and competences of secondary vectors (typical example: *Cx. pipiens,* and *Cx. tritaeniorhynchus*). The prevalence of the spatial epidemiology of JE epidemics and the virus transmission totally depends upon the ecological and environmental conditions combined with genetic and anthropological factors[52]. The longitudinal spatial extension of JE epidemics are possible on the consequences of change in land use / land cover categories (dry land agriculture to wet irrigation agriculture, including the terrace paddy cultivation), increase of availability of water resource for wet irrigation, and rainfall intensity and duration[48]. Multispectral satellite (MSS) data was effectively used for mapping of dengue, and chikungunya vector breeding grounds for study their environment, and the spatial and seasonal pattern of vector population fecundity [22].

13. LEISHMANIASIS AND VECTOR ECOLOGY

Visceral leishmaniasis (VL), or otherwise known as kala-azar is a chronic vector-borne disease caused by the parasite *Leishmania donovani* in India, is transmitted through the bites of an infected female sand fly *Phlebotomus argentipes* (*Diptera: Psychodidae*) [13-16]. The spatial distribution of visceral leishmaniasis is endemic in more than 80 countries, and about 0.2–0.4 million cases and 20,000–40,000 deaths each year, and 90% of cases are occurred mainly in the age group of <15 years children [1,2,13,16], and most predominantly occurred in the following six countries: Brazil, India, Ethiopia, Somalia, Sudan, and South Sudan[1]. VL vector sand fly *Phlebotomus argentipes* abundance is spatially thickness in the monsoon between June and September; profusion are most actively presented with temperature range between 27.5oC and 31 °C, and type of unique vegetation cover [15,16]. The active sand fly profusion spatially correlated and the seasonal pattern of highest risk leishmaniasis infections occurred during the spring and summer months [23]. Environmental variables including precipitation, aridity, elevation, soil types, soil types, soil depth, soil moisture, soil colour, soil water holding capacity, soil texture, soil pattern, soil moisture regime, slope, and elevation of the terrain and a composite maximum, minimum, and mean Land Surface Temperature (LST), vegetation cover and types, human dwellings peripheral to cattle sheds with mud floor and mud walls, alluvial and black cotton moisture soil grounds in and around the domestic areas, and Normalized Difference Vegetation Index (NDVI) are directly influenced the diversity and distribution of *Phlebotomus papatasi* and *P. sergenti* sand fly vectors, and has no significant or negatively correlated with aridity, slope and elevation [13-16]. Sand fly vector breeding fecundity has been progressively affected with the edible vegetation cover, growth, and density [16]. The areas with edible shrubs and land cover plants, alluvial soil, soil moisture (62-113 mm), altitude (12 m-1900 m), mean annual temperature (15°C-30°C), mean annual precipitation (274 mm-1212 mm), mean annual potential evapotranspiration (1264-1938 mm) are making unique environment suitable for living sand fly P. martini , and vector abundance. VL vectors namely; *P.orientalis,* and *P. papatasi*, are densely occurred where the area's most suitable with altitude (200 m-2200 m), mean annual rainfall (I80mm-1050 mm), mean annual temperature (16°C-36°C), and soil moisture (67-108 mm), alluvial and black cotton soils with alkaline (pH 7.2–8.5) [13-15]. Multispectral and microwave satellite data is enormously utilized for mapping landscape environment including soil types, soil moisture, texture and pattern, plants, and ecology of the sand fly vector abundance[13-16,23].

14. KYASANUR FOREST DISEASE (KFD) AND VECTOR ECOLOGY

Kyasanur Forest Disease virus (KFDV) is a tick borne vector borne disease belongs to the family virus of *Flaviviridae*, and it is serologically and genetically classified as *Alkhurma* Hemorrhagic Fever Virus (AHFV) [17], was recently identified in Saudi Arabia. KFDV has been endemic in the Karnataka State of Southern India for the past 70 years [53], and is life threatening for a considerable amount of people every year, since 2012. Kyasanur forest disease (KFD), hemorrhagic manifestations with a tick-borne viral disease, occurred repetitively in the unique forest environment, and became endemic for several years. Since 2012, it has been diffused to longitudinal belt in the western guards, and before it was restricted within the forest habitants in Shimoga district of Karnataka, and later spread to Uttara-Kannada, Dakshina-Kannada, and Udupi in Karnataka[53]. The first report of KFD registered in the Shimoga district of Karnataka, in India during 1957. The Ticks belong to *Haemaphysalis spinigera*, are the main vector transmitting the KFD virus while bites humans, and causes illness that can lead to fatal if not treated properly. The KFD disease epidemics are directly linked with climate season, deciduous forest cover, and red loamy soil types with high moisture contents; mostly it occurs during autumn and summer season i.e. before the Southwest and North-East monsoon season. During the monsoon, tick nymphs fecundity and the active vector prevalence in the forest ground floor is very high during the months between November and June (winter to summer). Probably, the both immature and adult ticks are travelled through the animals and birds movement while they return to cattle sheds or home nests near by the human dwellings, and subsequently, travelling or spatially spreading to the bordering districts in the sisters states in Western Ghats region where the typical unique eco-systems, ecology, and the environmental factors are arranged. In the Western Ghats, the evolution and spread of E-gene sequences was higher than that based on the whole genomes[53]. The KFD epidemics are occurred constantly, perhaps due to limited efficacy of vaccination as well as significant mutations in the KFDV strains, since 2012 across the North to South stretches in the Western Ghats region situated in the districts of Karnataka, Maharashtra, Koa, Tamil Nadu, and Kerala in the Western Ghats of South India[53].

Two doses of the vaccine are administered to individuals aged 7–65 years at an interval of one month, the vaccinated individual experienced heavy pain, and therefore, the local people are not interested or hesitated to take KFD virus vaccination. KFDV vaccine is produced basically from the formalin inactivated KFD virus of chick embryo fibroblasts by the Institute of Animal Husbandry and Veterinary Biological Studies, Bangalore [54]. Complex phenomena including climate, landscape ecology, forest cover types, and environments are acted upon by the prevalence of KFD, among which one of the chief mechanisms is the low coverage of vaccination in the endemic region, beyond all; the public is hesitating to booster vaccine doses. The vaccine has linked side effects with severe pain, and adding together, the number doses must be taken for five years continuously, are some potential deterring factors, in order to overcome these problems, safer and more effective vaccines are needed. Based on the recent trend of KFDV reports, the cases are increased, despite the repeated vaccination double doses have been given in the vulnerable community in the hot spot endemic districts of Karnataka, and therefore, the epidemic transmission could be extended geographically protuberance from the endemic region to entrancing for several neighbouring districts of other states of Maharashtra, Tamil Nadu, Kerala, and Koa, and the spatial diffusion has been occurred silently becoming endemic very soon in different horizontal patterns. Mapping the KFDV hot spot epidemic transmission, risk assessment, and the probability of spatial diffusion make an alert to the susceptible community, using Remote Sensing, Global Positioning System (GPS), and Geographical Information Systems (GIS).

15. SCRUB TYPHUS AND VECTOR ECOLOGY

Scrub typhus is caused by bacteria known as *Orientia tsutsugamushi (Rickettsiae), Rickettsiae* are small *pleomorphic* organisms transmitted to humans through bites of an arthropod vector infected chiggers (larval mites) belongs to the *Trombiculidae* family (*Leptotrombidium deliense and L. akamushi*) [18,19,55]. It is a re-emerging vector borne disease has medically public health importance of about 1 million cases reported every year, mortality rate is 1-50% if not treated properly, and more than 1000 million people at risk of infection around the geographically confined regions in the Asia Pacific region including Japan, China, Philippines, Australia, India, Pakistan, Tibet, Afghanistan, Indonesia, Maldives, Myanmar, Nepal, Sri Lanka, Thailand, and islands in the Asia Pacific region, and southern parts of Russia [1]. The first report of scrub typhus illness caused by *O.tsutsugamushi* was identified in Japan [18], during 1899. In India, scrub typhus vector populations are spatially attributed in the scrub or bush forest land, scrub cover hilly terrain, and transmit the disease throughout the year, and have differences in the seasonal patterns [19]. The rodents, especially wild rats are the usual hosts for scrub typhus, the field rodents and the vector mites are acting as reservoirs, and hence, the infection is disseminating in the human population throughout the year[18,19,55]. It has no significant ecology or environment, seasonal patterns for the year round infection, however, the positive relationship between vector abundance and the infection rate is highly determined by the monsoon seasons, and a spatial autocorrelation is attributed with seasonal pattern, and the increasing number of mites borne cases and vector fecundity has significantly associated and determined by the climate risk factors (rainfall, temperature, humidity), especially, in India, the infected rate is higher in both the Southwest and Northeast monsoon wet weather conditions [19,55]. The spread of scrub typhus extended its geographical limits to wider increase of infection in Chile, Peru, Africa, and the Arabian Peninsula regions, and causes acute undifferentiated febrile illnesses (AUFI) with high morbidity and death toll in the recent years [19]. In India, the prevalence of scrub typhus is reported from Tamil Nadu, Andhra Pradesh, Karnataka, Kerala, Himachal Pradesh, Uttaranchal, Jammu, and Kashmir, Meghalaya, Assam, and Nagaland, West Bengal and Bihar, Maharashtra and Rajasthan for several years[55]. However, no clear data pertaining to the disease burden, no surveillance systems for real time mapping of scrub typhus vectors and disease, and no prevent measures available in India, and therefore, mapping prevalence, risk assessment, ecology and environmental risk factors associated with spatial epidemiology of seasonal patterns, disease burden at the national level, and systematic surveillance systems, using GIS technique could possibly direct to better management, and epidemic control.

16. ZIKA VIRUS DISEASE ECOLOGY

Urgent need for the study of Zika virus disease ecology, is the emerging notorious public health problems [57,58], since 2017, especially in the region has tropical and sub-tropical climate and deciduous forest cover which is geographically stretched in the entire western parts of western guards belts; Zika virus has public health importance, because of the recent epidemics in the states of Rajasthan, Madhya Pradesh, and Kerala in India [57,58], and cumulative number of 70 cases clinically confirmed in the Kerala[58] in 2021. It seems to be emerging new wave of virus transmission certainly be affected to the affected community, especially in the Southern States of India. Zika virus has clinically been identified in to two ways of transmission; 1) through the Aedes genus vector mosquitoes, 2) through the sexual contact, these major types caused Zika virus transmission which belongs to the family of *flaviviridae*, and genus *Flavivirus. Zika* can trigger paralysis (Guillain-Barré Syndrome). In pregnant women, it may cause subsequent birth defects [57, 58]. Based on the recent reports, which may be grumbling the community and is multiplying the prevalence to increasing the cases 3 times to 4 times lead to become explicit life-threatening situation? Geographical distribution and Seasonal variation of *Aedes genus* mosquitoes' biodiversity: a Zika virus vectors in the border of Kerala State neighbouring residential villages in the entire Western Guards belt of Tamil Nadu, Karnataka, Goa, and Maharashtra. Mapping of Zika virus vector mosquitoes (*Aedes aegypti and Aedes albopictus*) is absolutely significant for the systematic surveillance using GIS for organization, planning, implementation, and control. Thus, the public health authority possibly will make prevention measures to control the Zika virus outbreaks in advance and monitoring the epidemic situation in the country, continuously.

Aedes aegypti and Aedes albopictus vector mosquito's density caused by the man-made containers (socio-economic variables), and the natural breeding habitats, and land use / land cover types, environmental risk factors, and climate determinants. The spatial extent of geographical distribution and the emerging magnitude of Zika virus epidemics are increased, mainly because of 5 important factors such as, climatic parameters, socio-economic factors, vector density, floating migrated population for employment, and sexual contact with Zika virus infected persons, subsequently leads to increase of Zika virus. There is a need for necessary research works on emerging Zika virus epidemics, and a proper outline of the geographical aspects of the Zika vectors distribution, and the seasonal variations of the vector abundance in the hot spot regions in association with different geographical physiographic climate, landscape, altitude, socio-economic, natural, and man-made ecological determinants. Therefore, there is urgent need for the study on the information relevant to the vector distribution, density, vector ecology, vector seasonal abundance, and the ecological determinants, and the probability risk of Zika virus, Immunity level among the human population in the villages, probability of Zika epidemics can be provide the picture of outline at a glance explaining the reality of the ground situation in each and every parts of the border villages of neighboring states. Probability of hierarchy level of Zika virus risk assessment based on the environment, climate, and socio-economic variables are reliable information for the future planning to control and management of the Zika virus epidemic transmission.

17. CONCLUSION

Physical factors including climate, landscape, and environment influence the life of the parasites in the vectors, but these have not, as yet, been discovered temperature changes, or landscape changes, or environmental changes alone has much impact on the parasite development, and it has controlled by all the risk factors combined with the complex of other factors acted upon in nature including man-made environmental transitions. The spatial epidemiology of VBDs biogeographically determined and varied in different regions. The prevalence of vector borne diseases is definitely limited with vector density. The vector fecundity is high in the areas where the suitable environmental determinant variables are presented. The ecological and environmental variables including monsoon climate and daily weather (temperature, precipitation, humidity), topography, soil types, soil moistures, altitude, slope, vegetation types, eco-climatic zones, land use / land cover categories (built-up-lands, agriculture, water bodies, forest cover, rivers/streams, pools, reservoirs. lakes, irrigation canals, transport networks, etc.,) are directly linked with both presence of vectors and VBD epidemics. Mapping the spatial distribution of vector mosquito's ecology and the geographical determinants of its range is considered to be essential for public health planning. As such, vector population were recorded occurrences with respect to space and time in association with explanatory covariates, and thus, construct a map to predict the probability of vector borne disease transmission risk zones under thread across the country. The final map derived from the spatial analysis and spatial modeling to identifying the resource classes, direction, risk areas, and seasonal pattern of risk prone areas vulnerable to probability of high or low risk of VBDs epidemics, and thus, public health programmers and health care planners choose an appropriate control strategy to resolve the epidemics problem in advance.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

The Author hereby declare that he has not used generative Artificial intelligence (AI) technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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