Mapping the Geographical Distribution and Seasonal Variation of Dengue and Chikungunya Vector Mosquitoes (*Aedes aegypti* and *Aedes albopictus*) in the Epidemic Hotspot Regions of India: A Step towards the Vector Control and Sustainable Health

M. Palaniyandi¹,*, T. Sharmila², P. Manivel², P Thirumalai², PH Anand²

¹ICMR-Vector Control Research Centre, Indira Nagar, Pondicherry-605006, India
²Department of Geography, Government Arts and Science College, Kumbakonam (Autonomous), (Affiliated to Bharathidasan University), Tamil Nadu, India

*Corresponding author: smp.geog@gmail.com

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**Abstract** *Aedes aegypti* and *Aedes albopictus* are known vector mosquitoes for several emerging arthropod-borne viruses (arboviruses) including dengue fever, chikungunya, Zika fever, Mayaro and yellow fever viruses across the world. *Aedes* species vector mosquitoes are blamed for the spread of dengue and chikungunya in India. Dengue and Chikungunya is the illustrious public health problems in the country, dengue has public health importance and cumulative burden to the affected community, especially in the Southern States of India, since 1991, and followed by the highest outbreaks of chikungunya in the Southern India, 2006. Dengue cases reported from 24 States and 3 Union Territories out of 34 States / Union Territories in India, and highest reports recorded in 5 major States (Tamil Nadu, Kerala, Karnataka, Punjab and West Bengal), during 2017. All the four serotypes of dengue virus (DEN-1, DEN-2, DEN-3, and DEN-4) are detected across the country various with space and time. Mapping the geographical distribution and seasonal variation of dengue and chikungunya vector mosquitoes (*Aedes aegypti* and *Aedes albopictus*) is absolutely significant for the systematic surveillance, organization, and implementation, accordingly, the public health authority possibly will make prevention measures to control the dengue epidemic earlier in advance and monitoring the endemic situation in the state as well as in the country, continuously [16,17,18]. *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. All the four serotypes of dengue virus (DEN-1, DEN-2, DEN-3, and DEN-4) are detected in India. The study has mainly focused on the major endemic districts in India, where the state of endemic has accumulative problems, and is grumbling the community. *Aedes aegypti* and *Aedes albopictus* are the known vector mosquitoes of dengue and chikungunya. The endemic districts have unique landscape terrain and land use / land cover pattern, and climate factors (precipitation, temperature, relative humidity, and saturation deficiency). The major landscape terrain has hilly, plain and coastal areas. The epidemic areas receive rainfall by both the southwest monsoon and the northeast monsoon from April to November (almost 8 months), and has the average temperature range of 22°C to 31°C, and relative humidity of 70 % to 90 %, and the present study contains the vector density is highly influenced by the maximum number of rainy days, and the occurrences of dengue epidemics clustered regions in India mainly where it receives annual mean rainfall ranging from 300 mm to 1200 mm. The spatial distribution and seasonal variation of vector mosquitoes (*Aedes aegypti* and *Aedes albopictus*) in the identified endemic districts are absolutely gripping the situation by seasonal variation in precipitation and temperature, land cover spatial variations, socio-economic, and ecological differences have directly affected the profusion of vector mosquitoes and the incubation period of the dengue and chikungunya virus, and thus, huge epidemics in the identified endemic districts along with entire state. Consequently, the nature and manmade environment is fuelling for the huge number of profusion of *Aedes* species mosquitoes in the epidemics area. Mapping the spatial distribution and seasonal variation of *Aedes aegypti* and *Aedes albopictus*, using Remote Sensing, and GIS technology could be an ultimate tool for functioning a dengue surveillance in the endemic districts as well as in the country, and thus, comfort to the public health experts to organize, implement and choose an appropriate control strategy for the prevention measures to control the grumpy situation in the dengue endemic hot spot regions in the country.
Keywords: mapping vector ecology, Aedes aegypti and Aedes albopictus, dengue and chikungunya vector, dengue control strategy, environmental determinants, climate parameters, land use/land cover, socio-economic factors, remote sensing and GIS

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1. Introduction

Aedes aegypti and Aedes albopictus (Asian tiger mosquitoes) [1] are vigorous day biting vector mosquitoes originated in Africa [2], prevalent in the tropical, subtropical, semi-arid, and temperate regions throughout the world [3], and spreads several emerging arthropod-borne viruses (arboviruses) including dengue, chikungunya, Zika fever, Mayaro and yellow fever viruses across the world (Caribbean (including Puerto Rico), Central and South America, Southeast Asia, and the Pacific Islands. In the United States [4]. The biology of Aedes albopictus breeding was more in the peridomestic container breeding habitats as surveyed [1]. Aedes aegypti is the main vector mosquito for the transmission of dengue and chikungunya and Aedes albopictus could possibly be acting as a secondary vector mosquito [5,6]. Aedes aegypti and Aedes albopictus vector mosquitoes are mainly responsible for the spread of dengue and chikungunya in India [7,8,9]. Dengue has clinically been classified into 2 major types such as dengue haemorrhagic fever (DHF) and dengue shock syndrome (DSS) caused by the dengue virus which belongs to the family of flaviviridae, which has been grumbling the community and is multiplying the prevalence to increasing the cases 3 times to 4 times lead to become explicit life-threatening situation due to lack of specific antiviral drugs or vaccine, and comprises four antigenically distinguishable serotypes (DEN-1, DEN-2, DEN-3, and DEN-4), transmitted obviously through the day biting Aedes aegypti and Aedes albopictus female mosquitoes [7,8]. A confirmed dengue case was turned in death reported first time in Kerala, 1997, subsequently, the situation was increased by every successive year and all the state to become endemic situation in the several districts [7,8,9,10], both in the urban and rural dwellings, the vector density and dengue epidemic prevalence are highly associated with number of rainy days per month and receives almost 7 months’ rainfall every year [7,8,9,10]. The Aedes adult mosquitoes are living in the shadow areas, and when cloudy is forming, the vector mosquitoes are very active and started human blood feeding during the day time [3], and the selected study districts have perfect environment for the increase of Aedes vector mosquitoes added with conducive environment, and thus, lead to longitudinal spread of dengue epidemics rapidly [10,11,12,13,14].

Mapping the geographical distribution and seasonal variation of dengue and chikungunya vector mosquitoes (Aedes aegypti and Aedes albopictus) is absolutely significant for the systematic surveillance, organization, and implementation, accordingly, the public health authority possibly will make prevention measures to control the dengue epidemic earlier in advance and monitoring the endemic situation in the state as well as in the country, continuously [16,17,18]. Aedes aegypti and Aedes albopictus vector mosquito’s density caused by the man-made containers (socio-economic variables) [11], and the natural breeding habitats [19,20,21], and land use / land cover types [41,42], environmental risk factors, and climate determinants [4,18,22]. The spatial extent of geographical distribution and the magnitude of dengue epidemics is keep on increased across the India (NVBDCP, 2019), mainly because of three important factors such as, climatic parameters (temperature, rainfall, and humidity, and saturation deficiency), consequences of reduced or asymmetrical monsoon rainfall and inadequate and irregular water supply leads to water storage practice in the metal or plastic containers for domestic purpose, socio-economic factors (low income and clustered settlements) [11], urban sprawl, population density and population movements, industrial and urban developmental construction activities improper solid waste management, and lack of awareness among the people [21], and subsequently leads to vector density and increase of extrinsic incubation period (EPI) of DEN virus and CKIK virus. Dengue cases reported in India is accelerated rend in India, since 2003, (NVBDCP, 2019). There are many research works published in the area of dengue epidemics which contains the essential and the importance of dengue surveillance, control and management of the dengue transmission, vector breeding habitats, dengue virus types, dengue incidence, etc., however, the planner has no proper outline of the geographical aspects of horizontal and vertical structure of the dengue vectors distribution, and the seasonal variations of the Aedes species in the country in association with different geographical physiographic landscape, altitude, climate, socio-economic, natural and man-made ecological determinants. The article entitled “South India under the grip of dengue again” published in the Down to Earth, 19th July, 2019, and headlined that Karnataka, Tamil Nadu, Telangana and Kerala, four are in South India of the five states worst-hit by the mosquito-borne disease, shows the present risky circumstances of the state under threat of dengue outbreaks. Therefore, the present study contains the information relevant to the vector distribution, density, vector ecology, vector seasonal abundance, and the ecological determinants at a glance explaining the reality of the ground situation in each and every parts of the country, and it has detailed account of mapping the spatial distribution and seasonal
variations of both immature and adult vector mosquitoes of *Aedes* species in the recognized endemic regions of India.

2. Study Area

The present study is included India as whole with special focus on the dengue endemic States of India (Figure 1). The study area has unique landscape terrains, land use / land cover, climate (precipitation, temperature, relative humidity, and saturation deficiency). The landscape terrain is classified in to three categories, i) coastal or plain areas, ii) mid land elevated with undulated landscape, and iii) highly undulated and hilly terrain where the major land use/land cover are i) coconut, plantain, groundnuts, fruits, edible oil seeds, pulses, black grams, wheat, and rice cultivation, ii) coconut, pulses, rubber plantation and pine apple cultivation, coffee, black pepper, cashew nut, and iii) tea, and spices, respectively [10,23]. Tamil Nadu receives the mean annual average rainfall of about 945 mm (37.2 in) of which 48% is through the North East monsoon, and 32% through the South West monsoon millimetre per annum, The average annual rainfall in Punjab is 639.9 mm, Delhi has receives the average rainfall amounts to about 800 mm, West Bengal is 1750 mm, Karnataka is 1248 mm, Andhra Pradesh is 940 mm, Telangana and 700 to 900 mm, Kerala receives an average annual rainfall of 2,923 mm, and Maharashtra has received the annual mean rainfall of 1007 mm. The average temperature is range of 21°C to 32°C, and relative humidity is always high throughout the year of 70 % to 90 %. Consequently, the nature and manmade environment is making conducing environment and is fuelling for the huge number of profusion of *Aedes* mosquito species in the study area where the density of dengue and chikungunya vector mosquitoes (*Aedes aegypti* and *Aedes albopictus*) are inflated, and thus, the dengue endemic has accumulative problems of health issues as well as economic loss and grumbling the people of affected community, and the accelerated trend in India by space over a time period of past 2 decades.

Figure 1. Dengue Epidemic States of India with >1000 confirmed reported cases in the states, during 2016
3. Data Source and Resources

Dengue and Chikungunya vector population details are collected from the secondary source of published research articles, and the dengue and chikungunya epidemic prevalence was collected from the state government public health department public domain and the National Vector Borne Disease Control Program (NVBDCP, 2012-2019), and the author’s research dissertation [23], 2013-2016, is used for the compiling, editing, and the mapping of geographical distribution and seasonal variation of the both immature and adult Aedes vector mosquitoes. The adult mosquitoes were collected from the domestic peripheral areas in the selected wards (settlements) of the endemic districts, and around the outdoor plantain areas within 1KM radius [21,23]. The adult mosquitoes were collected in the indoor house by hand held light trap, hand held mosquito nets, and mechanical aspirator. The immature Aedes species vector were collected from the house hold containers (plastic tanks, tree holes, water storage barrels, grind stone, cement tanks, flower vases, curing tanks, glasses, metal vessels, rubber tires, and plastic bottles and cups, mud receptacles, coconut cells, tender coconut cells, roof gutters, refrigerator drip pans, cement blocks, cemetery urns, bamboo stumps) in and around the house perimeter [1-36], and also from the areas of construction sites and stagnant water, containers used for the rubber milk collection, and pine apple leaf segments [23].

The name of study sites and the geographical coordinates are recorded for the digital mapping and linking of vectors data, using ArcGIS ESRI software. The geo-climatic data pertaining to the land /land cover using satellite data was used for the analysis, and climate parameters are collected from the source of author’s research dissertation [10,23], and the Water Portal public domain, respectively. The land cover data is obtained from the satellite data, and the digital image processing was carried out in the ERDAS Imagine environment. Climate parameters (rainfall and temperature) are collected for the further calculation of relative humidity and saturation deficiency, and it was compiled for further statistical analysis. The mean annual temperature, mean seasonal temperature, mean annual rainfall and the mean seasonal rainfall were calculated for the analysis. The year round vector densities, monthly mean vector density, seasonal average vector density in the selected study sites are calculated. GIS software ArcView and MapInfo professional was used for the mapping of vectors density both immature and adult mosquitoes in the dengue and chikungunya epidemic as well as endemic hot spot region in the country, and it was overlay with landscape, climate parameters, and land use/land cover categories. SPSS+ software was used for the statistical analysis of the geographical landscape, and climatic independent variables and dengue epidemic dependant variable to obtain the spatial association between the risk factors and vectors and epidemic transmission [10,23], and thus, derived the longitudinal spread of dengue transmission. On the first hand, derived the spatial auto correlation between land use/land cover and vector density, and secondly, derived the geographical association between the landscape and vector density, and thirdly, climate seasonal variations and the vector density, and subsequently, constructed the probability of hot spot regions of dengue transmission risk in Indian sub continent.

4. Epidemics and Discussion

The prevalence of Aedes aegypti and Aedes albopictus are the known vector mosquitoes of dengue and chikungunya, and the distribution is geographically ubiquitous across the country. The geographical distribution of dengue and chikungunya has extensively spread longitudinal epidemic transmission (Figure 2a, and Figure 2b), and has reported into three to four-fold magnitude of epidemic cases across the nation (Figure 2c, Figure 2d, and Figure 2e). Dengue cases reported from 24 States and 3 Union Territories out of 34 States / Union Territories in India [10,11] (Figure 2c), and highest report was recorded in 5 major States (Tamil Nadu, Kerala, Karnataka, Punjab and West Bengal) [44] during 2017 (Figure 2d). Tamil Nadu state alone accounted for 14.65% of the total dengue cases, and followed by Kerala 12.67%, Karnataka 10.82%, Punjab 9.74%, and West Bengal recorded to 6.8% reported in India [44] during 2017. In Tamil Nadu, it wildly spreads in coastal districts, and extended to mid-land regions, whereas, in Kerala, it affects almost all the districts. All the four serotypes of dengue virus (DEN-1, DEN-2, DEN-3, and DEN-4) are detected in the major endemic districts of Kerala, since 1973, where the occurrence of epidemics turned to become endemic and has accumulative leads to problems is grumbling the community [7,8]. The landscape terrain is the highly undulated and hilly terrain where the major land use/ land cover is rubber plantation and pine apple cultivation. The total geographical area used for rubber cultivation in the Kerala State is 5.45 lakh hectares, and followed by the area under pineapple cultivation is 11,262 hectors. The study area receives rainfall by both the southwest monsoon and the northeast monsoon from April to November (almost 8 months), and has the average temperature range of 21°C to 34°C, and relative humidity of 70 per cent - 90 per cent [10,23], which is creating the conducing environment for the extrinsic incubation period (EIP) of dengue virus in the selected endemic districts of Kerala (8-15 days at 30.8 and 23.4°C), the average incidence of dengue is Kerala 49.278, and has a significant association between the occurrence of dengue cases and climate risk factors [10,23], and the spatial distribution of both horizontal and vertical distribution of dengue cases have been strongly influenced by the seasonality of both rainfall and temperature in the districts where the potential transmission of dengue virus during the monsoon and post-monsoon periods from April to November [24,25,26]. The major endemic states in India viz., Punjab, Delhi, West Bengal, Karnataka, Maharashtra, Kerala, Andhra Pradesh, Telangana, and Tamil Nadu (Figure 2.a), and the longitudinal extension of epidemics in Odisha, Uttar Pradesh, Gujarat, North Eastern States (Assam), and Rajasthan (Figure 2b), are directly influenced by the geo-climatic variables. The probability map of Aedes species vector population density in India, shows the high risk of dengue and chikungunya epidemic.
transmission (red colour for the entire Kerala, North-South longitudinal belt, and followed by yellow colour area has moderately risk and blue colour low risk in association with dengue and chikungunya vector population (*Aedes aegypti* and *Aedes albopictus*) density (Figure 6a, and Figure 6b).

**Figure 2a.** District wise Dengue Epidemic in India, 2016, Source: NVBDCP, New Delhi

**Figure 2b.** District wise Chikungunya Epidemic in India, 2016, Source: NVBDCP, New Delhi
5. Spatial Distribution of Dengue Vectors

_Aedes aegypti_ and _Aedes albopictus_ are known main vector mosquitoes responsible for the dengue and chikungunya transmission in India [7,8,9]. Spatial dengue epidemic clustered are mainly associated with socio-economic, climate, natural and manmade-environment parameters and land use / land cover [10,23,27], however, there is no linear relationship between the climate parameters (temperature and rainfall) and sporadic dengue cases [27]. Remote sensing offers a quick and efficient approach to mapping of land uses/land cover and its changes over space and time, and the information on changes in resource classes, direction, area and pattern of land uses/land cover classes [41,42,45] for linking the geographical distribution and seasonal variation of dengue and chikungunya vector mosquitoes (_Aedes aegypti and Aedes albopictus_) form a basis for choose a comprehensive vector control strategy and management of the grumbling situation moving towards the future planning for sustainable health [10,11,13,21,23,28]. A geo-spatial analysis of vector borne disease transmission including dengue epidemics in India revealed that, both in the urban and rural dwellings, the vector density and dengue epidemic prevalence are highly associated with number of rainy days per month and receives almost 7 months’ rainfall every year [7,8,9,10]. A case study dengue vectors shows that it has no significance differences between the immature and adult mosquitoes in association with prevalence of dengue and chikungunya epidemics \( t = 0.950, p >0.05 \), the similar study was carried by the author in the Pondicherry Union Territory and the result shows that there is no spatial differences and seasonal variation between the rural and urban environment [13,21], and therefore, need of the appropriate vector control strategy for comprehensive vector control and management, must be focused mainly on source reduction, and beyond routine larviciding, a focal spraying is essential throughout the year, moving towards the control of widespread dengue transmission in the state endemic districts [6]. The high density of immature and adult mosquitoes found in the human settlement areas and clustered settlements where the community of people mainly have in low income and engaged by them self as daily wage groups [11,13,21]. 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_.

![Dengue Epidemics in India (2016)](image1)

_Figure 2c. Dengue Epidemic states in India, 2016, Source: NVBDCP, New Delhi_

![Chikungunya Epidemic reports In India, 2010-2018](image2)

_Figure 2d. Chikungunya Epidemic in India, 2017 and 2018. Source: NVBDCP, New Delhi_
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 demarked as susceptible to risk of dengue and chikungunya infection, dengue vector mosquitoes (*Aedes aegypti* and *Aedes albopictus*) distribution, and density is highly associated with different physiographic features landscape and altitude [7,8,9,10] vector mosquitoes' high density, moderate density and low density was attained where the areas <150 Meter, 150-300 Meters, and 300M-600 Meters respectively, and > 600 meters from the MSL hilly areas has no risk (Figure 3a), the similar results was spatially fitted to the Tamil Nadu State, and Pondicherry Union Territory of India (Figure 3b). And, a study was conducted by the author shows that *Aedes* species vector density is highly associated with the NDVI < 0.4 and < + 1 with presence of actively photosynthesizing vegetation where the under the cultivation of rubber plantation, and pineapple cultivation [10,23]. *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 [6,11,21,29]. 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 [30,31,32], and is fitted over the physiographic landscape, and altitude i.e. Hilly areas [7,8,9,10,23,31], Plain region [37], and coastal areas [21,30], and metropolitan cities, urban sprawl, and semi-urban areas [21,33]. Hierarchy of dengue risk assessment based on the environment, climate, and socio-economic variables are reliable information for the future planning to control and management of the epidemic transmission in both horizontal and vertical aspects [11,13,16,28]. Probability of Dengue Transmission in India, red colour indicate maximum probability, blue colour indicate low probability of epidemic transmission, and the spatial prediction dengue longitudinal transmission is spatially associated with altitude <600 Meters and land use / land cover categories (crop land and plantations) in the country, and the inferences of map overlay has perfectly fitted with high epidemic situation in the southern states of the nation (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 survey studies was carried out for the whole country [36] (Figure 4a, and Figure 4b) The use of GIS and Remote Sensing techniques effectiveness be proved to useful and effective tools offering answers to both the programmers and scientists concerned vector populations of the areas under threat of dengue epidemics. Mapping the spatial distribution of *Aedes aegypti* and *Aedes albopictus*, and the geographical determinants of its range is considered to be essential for public health planning. As such, *Aedes* 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 dengue epidemics transmission areas under thread across the country [10,23,41] provide guidelines concerning risk to choose the preventive control measures timely.

![Figure 3(a)](image_url) Altitude map of Tamil Nadu, India, dengue and chikungunya vector mosquitoes (*Aedes aegypti* and *Aedes albopictus*) distribution, and density is highly associated with different physiographic landscape features and altitudes, vector mosquitoes' high density, moderate density and low density was attained where the areas <150 M, 150-300 M, and 300M-600M from the MSL respectively, and >.600M hilly areas has no risk.
Figure 3(b). Altitude map of Kerala State, dengue vector (Aedes aegypti and Aedes albopictus) distribution, and density is highly associated with different physiographic landscape features and altitudes, vector mosquitoes’ high density, moderate density (blue and grey colour), and low density (red colour) was attained where the areas <150M, 150-300M, and 300 M-600M from the MSL respectively, and >.600M hilly areas has no risk.

Figure 4a. The occurrences of Dengue and Chikungunya Epidemics in the hot spot regions of India having elevation zones < 500 Meters. (Map source: Sudhakar Reddy C., et al., 2015, NRSC, India).
Figure 4b. The occurrences of Dengue and Chikungunya Epidemics and Aedes species vector population has highly associated with Land Use / Land Cover categories of Crop land and Plantations, and Built-up-land.

Figure 5a. The geographical distribution of Dengue and Chikungunya vector mosquitoes (Aedes aegypti and Aedes albopictus) and vector density are spatially associated with the areas where it receives the monsoon rainfall 500mm-1000 mm and followed by moderately associated with rainfall 1000mm-3000 mm (Map source: Sudhakar Reddy C., et al., 2015, NRSC)
Figure 5b. Mean monthly rainfall and Dengue and Chikungunya vector mosquitoes density

Figure 6(a) and 6(b). Probability Map: The geographical distribution of dengue and chikungunya vector mosquitoes (*Aedes aegypti* and *Aedes albopictus*) in the Indian Sub-Continent, red colour indicate high density, yellow colour indicate moderately density, blue colour indicate low density, Map source: Kraemer, et al., -Global Distribution of *Ae. aegypti* and *Ae. Albopictus*, eLife2015; DOI: 10.7554/eLife.08347.009
6. Seasonal Variations

A study of climate change and dengue transmission shows the impact of meteorological risk factors on widespread of dengue prevalence at the global contest (Hales S, et al, 2007). Significance correlation was observed between average rain fall with dengue epidemic cases (97%; r= 0.987, p value < 0.001) and it shows a clear dependency of dengue cases with climatic factors that a strong lag phase association between number of rainy days’ rains and epidemic cases [38]. The spatial distribution of dengue vector mosquitoes is highly influenced by the geo-climate factors [17,39], and the human environmental changes including urbanisation, industrialisation, tourism, etc., which results spread of both Ae. Aegypti and Ae albopictus to different environment, and hence, rapid diffusion of dengue sporadic epidemic situation was occurred in different part of the nations [15,18]. Dengue virus serotype-2 (DENV-2) of Cambodian origin in Manipur (North Eastern State), India was conducing with meteorological factors [40]. The present study contains the vector density and geo-climate risk factors, vector abundance is highly influenced by the maximum number of rainy days (18-21 rainy days/month), is being correlated during the Southwest monsoon period from the month of May to August, and number of rainy days (10-16 rainy days/month), during the North East monsoon from mid-September to mid-December, and has declined trend from the month of mid-December to mid-April, and has significance with rainy days [6,7,8,9,11], the occurrences of dengue epidemics clustered regions in India mainly where it receives annual mean rainfall ranging from 300 mm to 1200 mm (Figure 5a), and mean temperature ranging from minimum of 21°C and maximum of 34°C, and the relative humidity is > 70 and < 90 per cent, it makes conducing environment for the vector profusion from the month of March to August (6 Months/Year), and it is most suitable climate for the vector profusion and virus incubation period, and has statistically significant with epidemic in India (Figure 5a, and Figure 5b). Kerala state is one of the most affected state among the four states in the country which has perfect environment for the vector profusion and for the EIP of DEN and CHIK virus [6,24]. Aedes aegypti and Aedes albopictus vector mosquito density is high in both rural and urban areas and it is highly associated with water storage containers during the pre-monsoon period of mid-March to mid-May, and very high vector density has highly associated with amount of rainfall and the number of rainy days from the month of May to August, and gradually reduced till Mid-March (Figure 5b). Blood feeding pattern of Aedes aegypti and Aedes albopictus shows that 76.9 % and 75% respectively [6]. The extrinsic incubation period (EIP) and its varied with different climatic zones of India. The EIP in Kerala state range between 8-15 days, and it has controlled by the temperature range minimum of 23.4°C to maximum of 30.8°C and were controlled and simulated with daily
temperatures, and the result has statistically significant [24]. The vulnerability of dengue epidemics cases was reported from the selected endemic districts during the South West monsoon period from the month of mid-May to August, and North East monsoon period from the month of mid-November to mid-December [10,23]. Aedes aegypti both immature and adult was the only prevalent species during the post monsoon period in most of the settlement areas where the drinking water supply is irregular [6,7,8,9,10,13,21], with these available information, the google internet real-time web mapping technology could be used to mapping the recent epidemic transmission [46], and to be assessed the area under the risk of vulnerability [43], based on the Aedes vector population occurrences in association with geo-environmental variables, Figure 6(a), and Figure 6(b); Aedes aegypti is spatially distributed in the urban clustered settlement packets where the water-starved or water supply is inadequate, and the seasonality of the vector species is found almost throughout the year, and density is high in the hot spot endemic regions for the monsoon period of 6-8 months, and there is no difference of vector density in both rural and urban settlements. The peak of epidemics occurred during the beginning and ending months of monsoons period, and slowly reduced after the monsoon and during the hot summer. The spatial distribution and the seasonal variation of Aedes aegypti and Aedes albopictus are highly associated with altitude, land use /land cover, and rainfall season, house index, and the immature and adult density [10,48,49,50], and successively, the risk of dengue and chikungunya transmission as classified into low, medium, and high risk, and the probability of dengue and chikungunya epidemics transmission risk pattern in India, raster map derived, based on the probability of risk index value range between 0-1 assigned for each grid cell consist of 25 Sq.KM. (5KM X 5KM), because, the reality of the ground level situation in India has a village or a presents of human settlement in each grid cell is shows the representation of the real world (Figure 7), and thus, the geographical area was classified based on the vector density, seasonal variations relevant to the land use/ land cover, altitude and climate determinants [10,23,45,48,49,50].

And therefore, a multi-sectoral approach at the multi-level is needed to practice vector control and management to reach the benefit to the grass root level by the implementation of comprehensive vector control and management including the plan for making awareness among the human society, and also making a preparedness, prevention measures effect to control epidemics in both urban areas and rural settlements so as to manage the epidemic situation across the nation. The public health personnel joint hands with environmental scientists, medical geographers, urban planners, socialists, and the municipality corporation choose an appropriate control strategy moving towards the management of the epidemic situation early in advance.

7. Conclusion

The geographical distribution and seasonal variation of dengue and chikungunya vector mosquitoes (Aedes aegypti and Aedes albopictus) longevity, survival and density are highly determined by the complex of phenomenon, however, the study concluded that it is limiting with climate and man-made risk factors have influential on longitudinal transmission. The study concluded that dengue and chikungunya vector density, DEN virus and CHIK virus incubation are mainly influenced by the climate parameters. Therefore, the study of spatial distribution and seasonal variation of dengue vectors, mapping of probability of dengue transmission risk areas, based on the meteorological and the entomological information is a significant role in the epidemiology of the disease which gives the guidelines to choose an appropriate control strategy in public health aspects to change the grumbling situation. The integrated GIS, satellite imagery and statistical models assists researchers to predict the hierarchy of spatial distribution of vectors profusion in the rapidly changing different environment. Accordingly, the authors have schedule and research plan for the next phase study to develop the Ecological niche Modelling for Prediction of Dengue Epidemics (ENMPDR) in India to mapping the hierarchy of vector mosquitoes density, species distribution, habitat distribution, and seasonal variation based on the geographical variables (climate, environmental, topographical, land use / land cover, human/man-made) and socio-economic determinants approaches to the spatial prediction of dengue epidemic risk early in advance where different types of dengue virus was already occurred or to be occurred in different types of ecological circumstance.

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