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The environmental aspects of dengue and chikungunya outbreaks in India: GIS for epidemic control

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ABSTRACT
Background: The dengue and chikungunya epidemics have major challenging problems and have become essentially a public health importance in India for the recent years, and it has been transmitted by the *Aedes* genus (*Aedes aegypti* or *Ae. Albopictus*) mosquito vectors. The huge chikungunya epidemic cases was reported in 213 districts especially in South India during 2006 and it happened in India, after 25 years period of breaks. The epidemic was showing good improvement of spatially declining trend, however, the dengue epidemics were reported from 24 states / union territories of India with 37070 cases and 227 deaths during 2012 and it steadily increased to become a very serious threat to the public.
Materials and Methods: The ARC View 3.2 GIS was used for mapping the occurrences of epidemics situation in the country, geo-statistical analysis was carried out using SPSS 10.0, and ERDAS Imagine 8.5 image processing software was used for calibrating the NDVI value from IRS WiFS data.
Results and discussion: The spatial analysis of geo-climate and the determinant variables with the epidemic cases provided results that temperature was experienced with a range of 22 to 31 ^{o}C, and relative humidity of 70 % to 90 %, and rain fall providing most suitable environment for fueling the huge number of profusion of *Aedes* mosquito species, with 95% significant and 5 % precision. Dengue and chikungunya epidemics in major metropolitan cities across the country, and rural areas in Maharashtra, Haryana, Uttar Pradesh, Pondicherry and Tamil Nadu have been associated with the huge number of containers of damaged house hold things in the coastal areas making it suitable for *Aedes aegypti* mosquitoes breeding. The regulation of irregular drinking water supply was supplied once in a week or 10 days, and hence, the village people have the practice of drinking water storage in big plastic container/ vessels and cement container, which was statistically significant with chi-square χ^2 test, (P value <0.05). Chikungunya in Kerala was most associated with massive number of coconut shell used for collection of rubber milk in the rubber plantation in Kerala, and the massive pineapple cultivation in the state also fueling for dengue vector profusion in the state. The NDVI values of <0.4was due to the presence of actively photosynthesizing vegetation of rubber plantation, pineapple, forest cover, and hence, provided guidelines to stratification of areas under vulnerable to the dengue and chikungunya transmission.
Conclusion: Climate, landscape and environment play an important role and has influence on the epidemic transmission across the country. The application of remote sensing and GIS was potentially useful for stratification of transmission risk areas, and perhaps, useful for epidemic control and management in the country.

Keywords: Dengue, Chikungunya, *Aedes* mosquito, GIS mapping, Disease surveillance, Environmental determinants, Climate variables.

1. Introduction

Dengue and chikungunya epidemics have major challenging problems and have become essentially of public health importance in India for the recent years, and it has been transmitted by the *Aedes* genus (*Aedes aegypti* or *Ae. Albopictus)* vector mosquitoes [1,2,8,13]. Chikungunya epidemic was reported in 213 districts especially in South India during 2006 with lakhs of suspected fever cases reported, 15,504 cases were screened for blood samples and 1985 cases were clinically confirmed chikungunya [1], and the occurrences of epidemics were continued across the country, since 2006, and it happened in India, after 25 years period of breaks. The dengue epidemics were reported from 24 states / union territories of India with 37070 cases and 227 deaths during 2012 and it steadily increased to become very serious threat to the public [11]. Both dengue and chikungunya are transmitted by the *Aedes* genus (*Aedes aegypti* or *Ae. Albopictus*) mosquito vectors [1,3,7,13]. The environmental determinants have been creating conducing environment and manmade factors were responsible for the occurrences of disease epidemics across the country.

The chikungunya virus isolation and identification was carried out at the 311 government sentinel surveillance hospitals and 14 public referral hospitals working in the 35 states and the Union Territories of India [11]. GIS has been used for mapping of disease prevalence and analyzing epidemic situation and perhaps, assisting to controlling the epidemic situation at the national level.

2. Objectives

1. To map the prevalence of dengue and chikungunya epidemics in India
2. To study climate, landscape, and the environment of dengue and chikungunya transmission in India
3. To analyze the environmental determinants of dengue and chikungunya vector breeding habitats in the urban and rural environment, using remote sensing and GIS.

3. Rationale of the study

The dengue and chikungunya epidemic situation in the country has increased in recent years, and therefore, there is an urgent need for mapping the dengue and chikungunya transmission status in the country, and also to have a close monitoring on the disease epidemics. Therefore, the present study has been designed for mapping the occurrences of disease epidemics and to study the environmental aspects both of dengue and chikungunya epidemics. GIS tool has been applied in a scientific manner for mapping the prevalence of infection and disease transmission status in the country, and further, the environmental factors including manmade and geographical, climates, besides the factors related to host, parasite and vectors, demographic and developmental transitions was studied.

4. Materials and Methods

The available dengue and chikungunya data were collected from various sources including the National Vector Borne Disease Control Programme, (NVBDCP), New Delhi, India the Daily Newspapers, regional magazine, for preparation of chikungunya and dengue prevalence map respectively using Arc View 3.2 GIS platform (ESRI, NIIT-Chennai, India) (Fig..1 and.3a). The database was developed in the Dbase format using the MS Excel software and later on imported to the MapInfo Professional 4.5 GIS software platform and Arc View 3.2 Spatial analyst software platform for mapping the dengue and chikungunya epidemics in the country. The geo-statistical software SPSS 10.0 was used for importing the district wise thematic information of geo-climatic variables (mean annual temperature, mean annual rainfall, relative humidity, saturation deficit, altitude, soils types and population density) in the geo-statistical software platform, and was analyzed with disease epidemic dataset for assessing the role of climate and the environmental aspects of dengue and chikungunya transmission in India. ERDAS Imagine 8.5 image processing software was used for calibrating the NDVI value from IRS WiFS data. The geo-climate and environmental risk variables associated with the occurrences of dengue and chikungunya transmission was critically analyzed. The dengue and chikungunya epidemic has been spatially associated with environmental aspects of dengue vector breeding habitats.

5. Mapping prevalence of Chikungunya epidemics in India

There was a huge chikungunya epidemic especially in South India during 2006. Totally, 213 districts in 18 states/UTs of India with lakhs of people suspected with chikungunya fever admitted in the hospitals, 15,504 blood samples were screened, and 1985 cases was clinically confirmed cases reported in across the country during 2006. The present epidemic cases were reported from 18 states / UTs with 14277 clinically confirmed cases across the country during 2012 (Fig1 and Fig.2). The epidemic trend declined, but, it was replaced with dengue epidemics. A team of experts including the author visited the affected areas in South India during 2006 for investigation. It was observed that there was a south monsoon rain during summer, and it was found irregular drinking water regulation was supplied once in a week and hence, the village people have practice of drinking water storage using big containers. A huge vector population was found in the domestic and peripheral domestic containers, and enormous number of domestic animals (monkey, buffalo, donkey, dong, cat, rat, cow, goat, etc.) also found in the affected villages as known hidden host of dengue and chikungunya virus load [1,2,8].

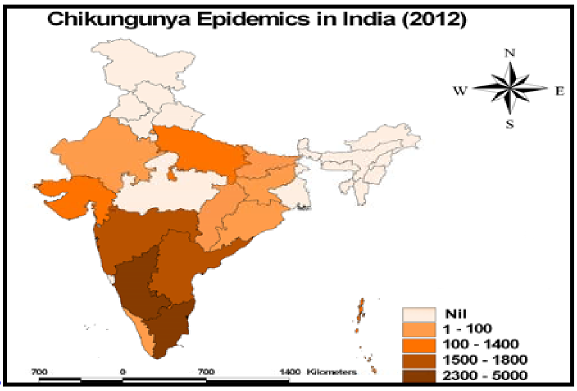

Fig 1: Chikungunya epidemics in India (2012)

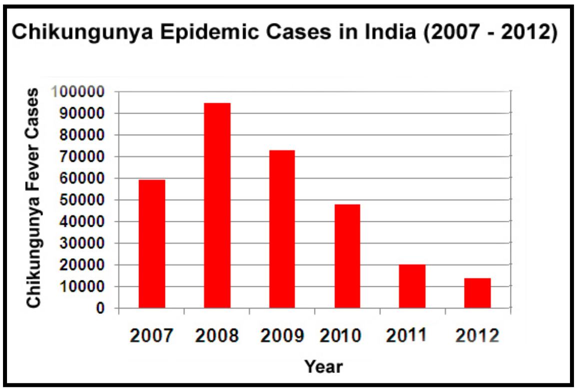

Fig 2: Chikungunya epidemics in India (2007-2012)

6. Mapping prevalence of dengue epidemics in India

Dengue and Dengue hemorrhagic fever (DHF) have been endemic in the Southeast Asia, Western Pacific, Africa, Sri Lanka, South America and eastern Mediterranean for more than 100 of years. But, situation was not very serious and it was almost insignificance in India. The first case of dengue was clinically confirmed and was reported in India during 1989. From 1991, onwards the epidemics of dengue have steadily increased to become a very serious threat to public and have become essentially a public health importance in India (Fig.3a, 3b and Fig.4). India has now become a host for all the four types of dengue virus (The Times of India, 2012; The Hindu, 2012). The dengue epidemics were reported from 13 states and Union territories (UTs) in different parts of India with thousands of clinically confirmed dengue cases and hundreds of deaths annually till 2011 (The Times of India, 2012; The Hindu, 2012). But, the situation was almost doubled and it was reported from 24 states / UTs with 37070 clinically confirmed cases and 227 deaths across the country during 2012, and 60 deaths in Tamil Nadu state alone was the highest number in the country followed by 59 deaths in Maharashtra as second position in the country. There were 9249 clinically confirmed epidemic cases reported from Tamil Nadu, followed by 6225, 3760, 3640, 2196, 1980 cases in West Bengal, in Kerala, from Karnataka, from Odisha, and cases from Delhi metropolitan city respectively (The Times of India, 2012; The Hindu, 2012; NVBCP, 2012).

7. Climate, landscape and the environments of dengue and chikungunya transmission

The environmental aspects of *Aedes* species vector mosquitoes breeding and both dengue and chikungunya epidemics across the country [2,3] for the recent years have been spatially associated and determined by the geo-environmental variables and the landscape of the areas, which are given below as details.

7.1. Remote sensing of landscape environment of the dengue transmission

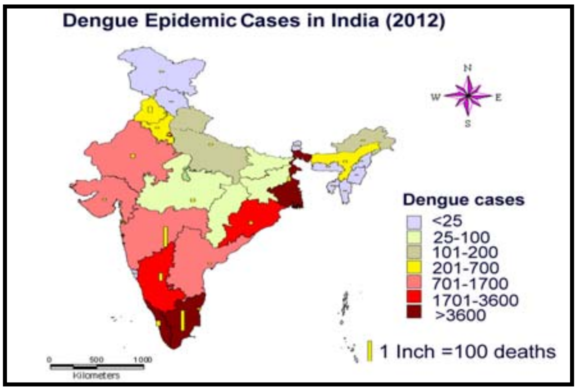

Fig 39(a): Dengue epidemics in India (2012)

The NDVI values of <0.0–0.2 corresponds to dense settlement areas in the metropolitan cities with breeding habitats positives for both dengue and chikungunya immature vector mosquitoes species (*Aedes aegypti* and *Aedes Albopictus*) positives, and the NDVI value > 0.2 and < 0.4 vegetation indicates the high income planned settlements and professional institutions, and < 0.4 and < + 1 with presence of actively photosynthesizing vegetation of rubber plantation, pineapple, forest cover, that provides guidelines to stratification of areas under vulnerable to the dengue and chikungunya transmission (Fig. 7).

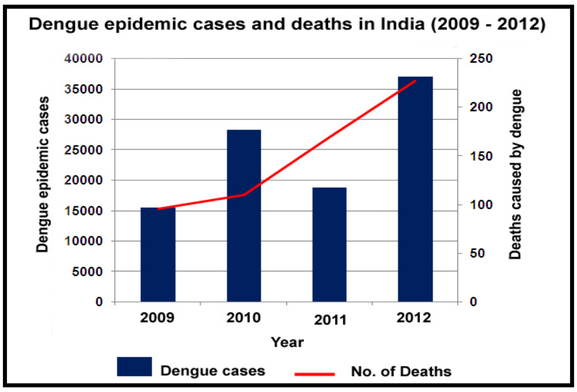

Fig 4: Dengue epidemic cases and deaths in India (2009 – 2012)

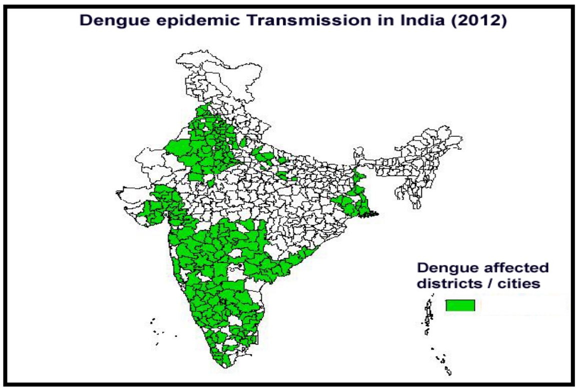

Fig 3(b): Dengue epidemic transmission in India during 2012, Source: NVBDCP

7.2. Climate variables on dengue and chikungunya transmission

Most of the dengue epidemic cases occurred in the metropolitan cities across the country and in some rural areas in Punjab, Haryana, Karnataka, Tamil Nadu, Uttar Pradesh and Maharashtra, where the environmental factors like humidity, temperature, and rainfall are known determinants of dengue vector development. The climate variables, temperature was experienced with a range of 22 to 31 ºC, and relative humidity of 70 to 90 %, and rain fall providing most suitable environment for fueling the huge number of profusion of *Aedes* mosquito species breeding during the monsoon climate season of both southwest monsoon and the northeast monsoon from April to November and the vulnerability of epidemics reported during the months of mid July to mid November period of the year, and the results obtained from the multivariate logistic regression model, the spatial association between the geo-climatic variables and the dengue and chikungunya epidemics was statistically significant with mean annual temperature $r = 0.638$, and p value < 0.05, relative humidity has result of $r = 0.674$, p value <0.05, and the cumulative effect of $r = 0.78$, $p<0.01$), and was perfectly fit on the dengue and chikungunya transmission risk zone, with 95% significant and 5 % precision, confidential interval of (CI= 0.64 to 0.0.793, n=94), n= Number of districts, and estimated error of 2.6 % to 3.8 %.Hence, the temperature and relative humidity has been providing most suitable environment for fueling the huge number of profusion of *Aedes* mosquito species breeding during the monsoon climate season of both southwest monsoon and the northeast monsoon from April to November and the vulnerability of epidemics reported during the months of mid-July to mid-November period.

7.3. Landscape environment of the dengue transmission

Dengue and chikungunya epidemics were reported from the coastal districts of Pondicherry and Tamil Nadu where the areas were marked for prone to tsunami and cyclone, since it was associated with the huge number of containers of damaged house hold things in the coastal areas suitable for *Aedes aegypti* mosquitoes breeding. The chikungunya in Kerala was most associated with massive number of coconut shells used for collection of rubber milk in the rubber plantation in Kerala (Fig. 5), and the massive pineapple cultivation in the state also fueling for dengue vector profusion in the state (Fig. 6), which has been the most suitable climate condition (temperature and relative humidity) for year round enormous quantity of *Ae. albopictus,* mosquitoes breeding in the Southwest monsoon.

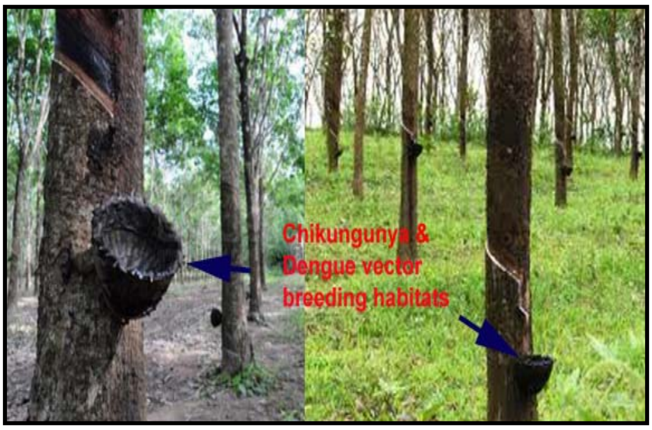

Fig 5: Dengue & chikungunya was most associated with massive number of coconut cell using for collection of rubber milk in the rubber plantation in Kerala

Fig 6: The massive pineapple cultivation is the ideal ground for profusion of dengue & chikungunya vector (Ae. *aegypti* and *Ae. Albopictus*) mosquitoes.

7.4. Defective rainwater harvesting structure and *Aedes* species breeding

Dengue and chikungunya epidemics were reported from the coastal districts of Pondicherry and Tamil Nadu where the areas were prone to tsunami and cyclone, and hence, with huge number of containers of damaged house hold things in the coastal areas making it suitable for *Aedes aegypti* mosquitoes breeding. Productivity of defective Rainwater harvesting structures (RWHS) was fueled for dengue vector breeding and vector population profusion) huge number of breeding habitats in the domestic and peripheral domestic areas. The defective rainwater harvesting structure accounted to 20 to 35%, and has been supporting profusion of dengue and chikungunya vector mosquitoes (*Aedes* sp.) breeding of 12 per cent of the total breeding habitats in the both urban and rural areas in Tamil Nadu state and Pondicherry union territory of India, and was statistically significant with χ^2 test, (P value <0.1). The breeding habitats were containers found in the outdoor domestic areas that contributed to more than 80 % of the *Aedes* species vector breeding, and statistically significant with chi-square χ^2test, (P value <0.05)

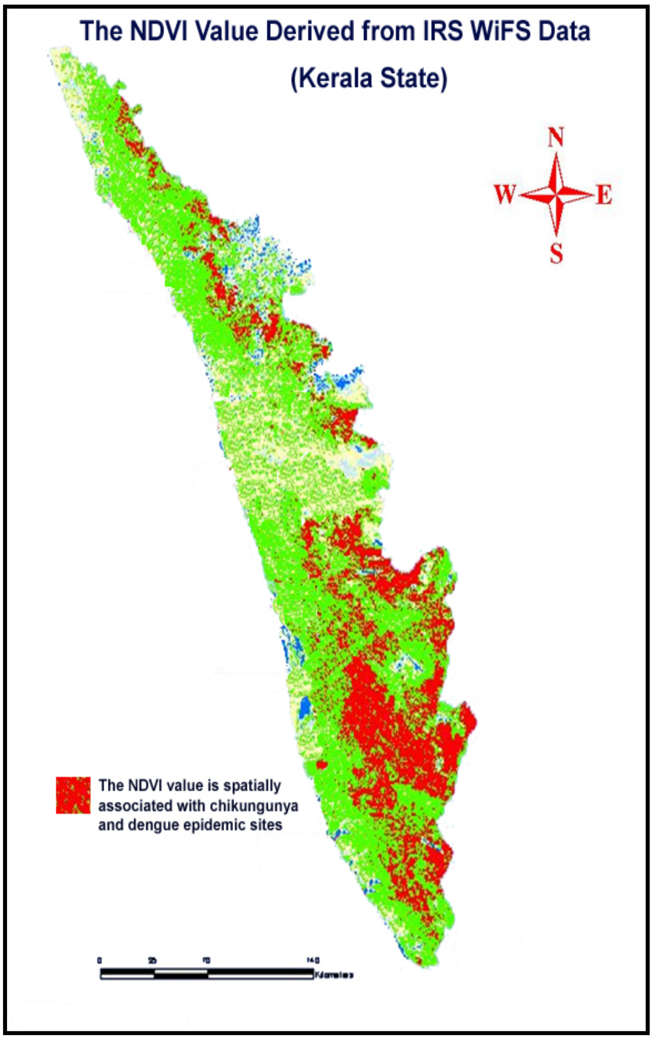

Fig 7: The spatial association between the NDVI value of IRS WiFS data and dengue and chikungunya epidemics transmission areas in Kerala state.

7.8. Other environmental risk factors of dengue transmission

The occurrence of dengue epidemic was determined by multiple factors, including climate, landscape, and the environmental dimensions that affect population biology, development, and behavior of vectors, as well as dimensions that determine the population biology and natural history of the viruses, including behavior of humans. The known occurrences of *Aedes* species are related to raster (grid format) geospatial datasets describing aspects of the climate, landscape, and the environmental landscape, to derive a quantitative multivariate model. The regulation of irregular drinking water supply was supplied once in a week or 10 days, and hence, the village people have practice of drinking water storage using big plastic container/ vessels and cement container, was statistically significant with chi-square χ^2 test, (P value <0.05). The replacement of bottled cool drinks by consuming the tender coconut was welcomed, but, a gigantic level of disposal of tender coconut shells found in the major cities of highways where the place of floating population was important for tourist attractions and, the vendors coffee bars, hotels and the petty shop business in the highways, serve them cool drinks and tea, coffee milk etc in the disposal cups. There were a large number of domestic animals found (monkey, buffalo, donkey, dong, cat, rat, cow and goat,)in the affected villages of Andhra Pradesh, Tamil Nadu, Maharashtra, Pondicherry and Uttar Pradesh, as known hidden host of dengue and chikungunya virus load, (CI= 0.67 to 0.0.796, n=40), n= Number of samples in the study areas examined, CI = 95 %, with the estimated error of is < 5 % (2.2 % to 3.9%),

7.9. Socio-environmental risk factors on dengue transmission in India

Lack of awareness in common people about the vector mosquitoes, disease transmissions, vector breeding habitats and the source reduction of vector mosquitoes breeding habitats. .More than 65 % of the entomologist posts were kept vacant in the country, as on 2012. Based on the newspaper sources [9,12], moderate rain during the summer, a week interval of drinking water supply, absence / negligence of block wise periodical entomological survey of dengue vectors for source reduction of vector breeding and lack of awareness of the common people are the causes that are collective responsible for creating conducing environment for fuelling for propagation of chikungunya vectors and chikungunya epidemics in different part of the country during 2012.

8. National disease surveillance and control systems

The National vector-borne disease control (NVBDC) has networked with the national research institutes including the ICMR for vector surveillance, disease control and management of the epidemic situation in the country. The present situation has instigated a plan for both vector and disease control operation in advance where the problem of vector proliferation and the occurrence of chikungunya and dengue epidemics were very serious problems in India. Therefore, the web mapping GIS for customized embed mapping of disease prevalence, entomological parameters, sources of vector breeding habitats, epidemiological information, environmental and climate variables associated with dengue and chikungunya disease epidemics [2-6].

9.1. Web mapping GIS for disease monitoring and control in India

GIS has not only been assisting in updating and mapping the disease prevalence of dengue and chikungunya prevalence, but also, becoming the important supporting tool for chikungunya surveillance and public health information systems, perhaps, decision making tool for controlling the chikungunya and dengue epidemics. GIS for customized embed mapping for disease surveillance and health information management systems in India has less than 10 % of GIS applications. Therefore, the urgent need for web mapping GIS for controlling the present situation of chikungunya epidemic prevalence in the country was taken. The user friendly internet GIS using API for embed mapping of past and present situation of the disease surveillance of chikungunya and dengue prevalence, controlling measures including the controlling measures for source reduction of vector breeding, ongoing disease control program, allows integration of data from any desktop data base software or worksheet to the head office server on ODBC facility. It has facilities to update the data from different nodes or centres and to pool at one place as the nodal office.

Perhaps, the GIS tool allows the online database connectivity (ODBC) for updating and mapping the real time epidemiological information for quick and clear visualization of the disease with site specifications from anywhere in India, and thus, a conceptual frame work of the present study of web mapping GIS application programming interface technology should be used for mapping, updating the real-time epidemiological information, monitoring the spatial distribution of chikungunya and dengue epidemic cases, and action plan for control measures by source reduction of vector breeding at the village level / block level and it has to be implemented in collaboration with district public health departments of state governments for implementing the chikungunya disease control operation at the national level successfully.

The case history of the occurrences of the chikungunya and dengue epidemic cases and the detailed epidemiological information relevant to patient's age, sex, site specification, name of the disease, viciousness of the disease, nature of the disease (migrant or indigenous), occupation, geographical location, reiterate of the disease/ number of times, season and duration of the disease occurrences are carefully mapped with API in web mapping GIS for updating the disease information. In collaboration with public health departments of state governments, the data containing the epidemiological information of chikungunya epidemics cases, the entomological parameters and the conducing environmental parameters of chikungunya vector propagations and disease transmission has to be entered in the geo-database engine for web mapping GIS application programming interface (API) for developing a simulation model for prediction of chikungunya outbreaks at least 2 weeks in advance [2,3].

The virtual Global positioning systems (GPS) instruments has been used for collecting the real time information on the site specifications of breeding habitats of *Aedes* mosquitoes (water storage plastic and cement containers, tires, plastic cups, coconut cells, tree holes, flower vessels, fridge, stone grinder, etc.,) and the victims of disease epidemic cases nearer to the host availability. This information must be updated every 2 weeks / fortnight of the every month. The information collected from various field stations in different part of the country has to be sent subsequently to the headquarters. The web mapping Python API has been mainly used to customize embed mapping of GPS based information of *Aedes* species mosquitoes vector breeding habitats, converting information between geographic site specifications with coordinate of geometric projection. Thus, the current problem of epidemic situations could be analyzed and perhaps, given solutions for precaution measures and action plan for controlling the present situation of chikungunya and dengue epidemic transmission in the country.

9.2. Solution for dengue and chikungunya epidemic control and management

It is well known fact that no vaccine is available for treatment of both chikungunya and dengue fever in the world so for, and hence, the source reduction of vector breeding habitats, making awareness among the people, and prevention measures to protect from aggressive day biting *Aedes* mosquitoes are the best way of control of disease epidemics. The intensive and regular reconnaissance survey has to be conducted with the interval period of once in 10 to 15 days in the major cities in the highways where the floating population of tourist attractions, and further, the survey may be perhaps extended to the areas of villages and small towns located in the buffer zones of 15 to 25KM radius along the highways.

Web maps offering GIS analysis have been frequently used in commerce, engineering, agriculture, business networks, law enforcement and forestry. However, web maps using GIS analysis for disease surveillance and health information management systems in India are less than 10% of all GIS applications. There is an urgent need of web maps that could use GIS analysis to depict how chikungunya and dengue spread across India. Layers of information would enrich these maps ever further. Detailed maps showing the pattern of disease transmission will play a vital role in controlling vector breeding. The epidemiological information of chikungunya and dengue cases, entomological information, breeding habitats and the environmental determinants of climate variables has been updated for overlay analysis with the geographical distribution of disease epidemic maps, and thus, generate layers information for spatial prediction of disease epidemics in the country. The updated information relevant to the chikungunya vector density, temperature, relative humidity, saturation deficit, precipitation, house locations, breeding site specifications has to be entered in to the web mapping GIS engine for monitoring the real time situation in the country [2,3].

10. Conclusion

Climate, landscape and environments determinant variable play an important role and has influence on the epidemic transmission across the country. The application of remote sensing and GIS is potentially useful for stratification of transmission risk areas, and perhaps, useful for epidemic control and management in the country. Perhaps, the system would allow integration of data from any desktop, database, software or worksheet. It will facilitate updating of data from different nodes or centers. Nodal offices will be able to collate the data within no time. Mapping past and present situation of the chikungunya and dengue surveillance will enable the administrative and the healthcare system to control the wildfire-like spread of these diseases. It could be used to map site specifications of chikungunya and dengue vector breeding habitats (house locations, water storage plastic and cement containers, tires, plastic cups, coconut shells, tree holes, flower vessels, refrigerators, drains, wells, pools and tanks) in the domestic and peripheral domestic areas. It could be used for converting the information between geographic geometric projection and the object information, and hyperlinks of spatial and non-spatial data. This technology could be essentially useful for the ongoing disease control operations and for decision making tool for taking appropriate measures for dengue and chikungunya epidemics control and management in future at the national level [2,3]. The GIS tool could allow the online database connectivity (ODBC) for updating and mapping the real time epidemiological information for quick and clear visualization of the disease with site specifications from anywhere in India.

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