Forecasting Spatial Distribution of Japanese Encephalitis Occurrence- A Remote Sensing and GIS Based Study in Assam, India

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Abstract

Japanese Encephalitis (JE) is one of the dreaded mosquito borne viral diseases mostly prevalent in South Asian countries including India. It is important to study the detail of the JE affected areas in terms of environmental and social factors that determines the outbreak of the disease. A comprehensive study was conducted during the period 2003-2007 in Dibrugarh, a JE endemic district of Assam. Effect of landscape and socio-economic factors on mosquito vector density was investigated with remote sensing and Geographic Information System (GIS) inputs and developed the methodology for predicting spatial distribution of occurrence JE in the district. The methodology was validated during subsequent 5 years (2008-2012) and accuracy of forecasts has been assessed. Wetlands have been found to be the most preferred habitat type for majority of the JE transmitting mosquitoes followed by paddy growing areas and ponds. Based on the spatial distribution of habitat types, villages in the district divided into three categories of vector abundance and hence the risk of JE. Among socio-economic determinants, pig rearing habitat of the villagers have been found to be most significant. Based on the pig rearing distribution pattern in the village, all the villages have been categorized into three categories of JE virus reservoir abundance viz. high, medium and low. Along with these two categorization approaches, villages were also categorized into three relative scale based on retrospective data on disease intensity. Final JE risk map was prepared with integration of vector abundance map with the map of host abundance and retrospective disease intensity in GIS domain. JE risk maps were prepared at the beginning of the disease season that is at the beginning of April for past five years (2008-2012). Actual cases occurred in the district was overlaid on the JE risk map to verify the accuracy of forecasts. It has been observed that about 70-81% JE cases reported from the High JE risk areas identified under the study during past five years (2008-2012).

1. Introduction

Japanese Encephalitis (JE) is a dreaded vector (mosquito) borne viral disease mostly prevalent in Asian countries including India. Virus from wild birds through vector mosquitoes spreads to peri-domestic and domestic birds and then to mammals like cattle and pigs, etc. and eventually spills over to man. JE Virus has been isolated from about 30 species of mosquitoes world-wide which fall under 5 genera viz., *Culex, Anopheles, Aedes, Armigeres and Mansonia*. However, only a few species meet the requirements to be classified as important vectors (Vythilingam et al., 1996). Since the first record of JE case in India in 1955 in Tamil Nadu followed by isolation of JE virus from wild caught mosquitoes in 1956, in the last couple of decades, epidemics of JE have occurred in the states of West Bengal, Assam, Manipur, Nagaland, Uttar Pradesh, Bihar and Goa in addition to South India (Mohan Rao et al., 1981, Prasada Rao et al., 1982, Narasimham et al., 1988 and Khan et al., 1996). JE cases have attained alarming proportions to pose as a major public health problem in India, more so due to unavailability of any cure for the disease and due to its very high case: fatality ratio (Kabilan et al., 2004). Geospatial techniques combining of Remote sensing (RS) Geographic Information System (GIS) and Global positioning system (GPS) have been emerged as effective tools for the surveillance of

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habitats, densities of vector species and even prediction of the incidence of the diseases, which has opened up new vistas in the epidemiology of malaria and other vector borne diseases (Dhiman, 2000). Since 1985, the Centre for Health Care Application of Aerospace Related Technologies (CHAART) has taken projects on the application of Remote Sensing (RS) and GIS technology to human health problems in China. GIS has been used in surveillance of vector borne disease by many workers (Hendrickxy et al., 199, Hugh Jones, 1989 and Jeganathan et al., 2001). There have been different applications towards surveillance of mosquito vector habitats and risk assessment with the use of geospatial techniques. (Barnes and Cibula, 1979, Beck at al., 1994, Glass et al., 1995, Abelardo et al., 2000 and Handique et al., 2005). The risk of contracting mosquito borne diseases is a function of the spatial and temporal pattern of vector breeding habitats and also of the interaction between vector and people and vector and the reservoir (Hay et al., 1997). Recent development with advanced spatial and geostatistical analysis has further facilitating in complex analysis and identification of disease hotspots for timely intervention measures. (Handique et al., 2011)

2. Materials and Methods

2.1 Study Area

The study was carried out in Dibrugarh district of Assam state located in the north eastern part of India considering the severity of impact of JE and its perennial occurrence. Average annual case load in Assam during the last two decades since 1980 has been 295 – the average annual incidence per million population being 12.5. Dibrugarh district alone shared a burden of 37 cases per million population. The district covering a geographical area of 7023.9 sq km lies between 27° 15′N - 28° N Latitude and 94° 45′E - 96° E Longitude. The District is covered under six Primary Health Centres (PHCs) *viz.* Barbaruah, Lahowal, Panitola, Tengakhat, Khowang and Naharani for monitoring and providing health care services in the district.

2.2 Collection of JE Case Data

Data pertaining to the JE cases were collected from the office of the Joint Director of Health Services in Dibrugarh district and from the Office of the Directorate of Health Services, Guwahati, Assam. Average disease incidence per unit population was calculated based on the PHC wise census records collected from the respective PHCs compiled under National Vector Borne Disease Control Programme (NVBDCP). Data on socio-economic status, pig, poultry, cattle farming practice, flood proneness of the areas and personal protection measures adopted for prevention of mosquito bites, etc. were collected through a socio-economic survey.

2.3 Mosquito Collection and Serological Studies

Adult mosquito collections were conducted at fortnightly intervals from each PHC i.e. once a month from each of the eight collection sites. One cattle shed housing 6-8 cattle in each village was pre-identified for the adult mosquito collection and collection commenced 30 minutes after sunset and continued for one hour. The collected mosquitoes were brought to the laboratory in Barraud cages of 12 cubic inches size wrapped in moistened muslin cloth. Mosquitoes were identified live under a binocular stereoscope by trained personnel following standard identification keys after inactivating them on a Chill Tray (American Biophysics Corp, USA) at low temperatures (0-2ºC). Mosquitoes were pooled species wise and stored in 2ml centrifuge vials limiting the numbers to 50 in a pool. The vial caps were tightened and secured by adhesive tape, labelled and stored in liquid nitrogen cans for JE virus incrimination studies. Mosquito densities were expressed in Man Hour Densities (MHD) (mosquito collected per man per hour, i.e. total collection of a particular dusk hour divided by number of persons engaged in collecting). Immature mosquito collections were conducted simultaneously with the adult collections. Standard white plastic dippers with 200ml water holding capacity fixed to an extendable aluminium handle were used for the purpose. Dips were made in all probable mosquito breeding habitats like paddy fields, fallow fields, irrigation canals, ponds, wet lands, etc. and the mosquito larvae and pupae thus collected were stored separately habitat wise in plastic containers. The containers were labelled and each of the larvae/pupae was link reared in the laboratory. Emerged adults were identified and recorded. Vector incrimination was done by Xeno-diagnosis (Rosen and Gubler, 1974). ELISA test was conducted on the samples for vector incrimination by using JE virus specific and arbovirus specific monoclonal antibodies (supplied by National Institute of Virology, Pune). Serological studies were conducted by Regional Medical Research Centre NER (ICMR), Dibrugarh following standard procedures.

2.4 Delineation of Mosquito Breeding Habitats using Remote Sensing Data

Satellite imageries of different sensors were acquired from National Remote Sensing Centre (NRSC) Data Centre, Hyderabad, India ensuring cloud free condition. After acquisition of satellite data in the form of a CD-ROM product, it was subjected to various pre-processing techniques in order to obtain geographically referenced data. IRS LISS III images having spatial resolution of 23.5 meter were acquired during the study period 2003-2007 and were used for delineation of the land cover types. Supervised classification approach based on maximum likelihood algorithm (Jensen, 1996) was operated upon the image using purified signature sets generated for different land cover types. Among different land cover types, mosquito vector habitats such as river, stream, wetland, water logged areas, agricultural land, tea garden, forested area, settlements, etc. were identified. Accuracy of classification was tested with Kappa coefficient which was recorded as 0.861 resulting an overall classification accuracy of 88 %.

2.5 Measure of Mosquito Vector Abundance

Vector abundance is measured in terms of Man Hour Density (MHD) of adult mosquitoes and species diversity of immature mosquitoes. Mosquito collection done by skilled technicians as discussed in section 2.3 has been converted into MHD. A three km buffer area around the sample collection point has been extracted in all the study villages assuming it to be an approximate flight range of mosquito. Extensive mapping of the mosquito habitats within the buffer area has been made using remotely sensed data along with ground truth verifications. MHD has been correlated with the per cent of area under different vector habitats within the buffer area and put in relative scale of 1-3, indicating High, Medium and Low mosquito density. On the other hand, diversity mosquito vectors determined by identifying different immature mosquitoes collected from selected field sample collection sites as described in section 2.3. Diversity of mosquito vectors was measured with Shannon Weiner Diversity Index (Shannon and Weaver, 1949) which is given by:

$$\overline{H} = -\sum_{i=1}^{n}\left[\left(n_i/N\right)\log_e\left(n_i/N\right)\right]$$

Equation 1

Where $\overline{H}$ is the index value and 'n_i' number of species and 'N' is the total number of species in that habitat type. Different habitats have been found to have different levels of diversity indices, which were put in relative scale of 1-3, indicating High, Medium and Low mosquito diversity. Both mosquito vector density and species diversity have been taken into consideration for categorizing villages into three categories of vector abundance viz. High, Medium and Low.

2.6 Categorization of Villages under Different Categories of JE Risk

Three level of categorization of the villages into a relative scale of High, Medium and Low mosquito density areas was done based on vector abundance, host abundance and intensity of retrospective disease cases at village level. Pig rearing habits of different communities in the study area has been assessed with the socio-economic survey carried out in the villages near ground sample collection points. Information on village wise community distribution has been collected from office of the respective Block Development Officer. Villages of the district have been categorized according to the intensity of case load since 1985. Villages having a case load of 5 and above reported over the years categorized as High JE intensity village. Villages having case load 1-4 have been categorized as Medium JE intensity area. Villages which have never reported any JE case since 1985 have been categorized as Low JE intensity areas.

2.7 Data Analysis

Satellite data analysis for delineation of land cover and mosquito vector habitats as per methods described in section 2.4 have been carried out with ERDAS Ver.10 software. Creation of buffer around the field sample collections sites and integration of layers were performed using and ARC GIS 9.3 Software (Lawson, 2001 and Lee and Wong, 2001). Statistical analyses comprises of determining correlation (Pearson Coefficient = r) between mosquito vector density and habitat types the have been done using Microsoft Excel. Whether the calculated value of r is significant or not is tested with the help of t test, where t is given by:

$$t = \frac{r}{\sqrt{1-r^2}}\sqrt{(n-2)}$$ with (n -2) degrees of freedom.

Equation 2

3. Results and Discussion

3.1 Determination of Vector Habitat Preference

Figure 1 gives the variation in terms of frequency of occurrence of different mosquito species. It is seen that species viz. *Cx. Vishnui, Cx. Gelidus, Cx. quinquifaciatus, An. Hyrcanus, An. Annularis*, have high occurrence in almost all the habitat types. High number of occurrence of most of the mosquito species in wetlands shows it to be the most preferred habitat, particularly for *Cx. Vishnui, Cx. Gelidus and Cx. bitaeniorhynchus. An. hyrcanus* is observed to be available in all habitats in high numbers except in habitats viz., sewage canal, and ground pool. From the vector diversity analysis it is seen that wetland contributes the maximum diversity, and it is seen from the graph that it also supports high occurrence of the vectors. Wetland is found to be the most preferred breeding habitat in majority of the sample collection points. Ponds and deep water paddy areas follow closely as other preferred breeding sites for a number of mosquito species as indicated by the diversity indices (Figure 2). As the area under paddy cultivation is the largest, they are the major contributors in building up of vector density in the study area.

3.2 Observations on Host Abundance

Tribal communities viz. *Sonowal Kachari, Boro Kachari, Deori* and *Mising* communities are found to have highest pig population followed by other communites viz., *Ahom, Chutia, Moran, Motok and Mesh.* Communities viz., *Tea tribe, Nepali and Bengalis* have relatively less pig rearing habit. Lowest population of pig has been observed among general castes viz., *kalita, Brahmin and kumar.* Based on the community distribution pattern in the village all the villages have been categorized into three categories pig population viz. High, Medium and Low pig population areas. This has indicated the abundance of JE virus reservoir and hence the risk of JE the village.

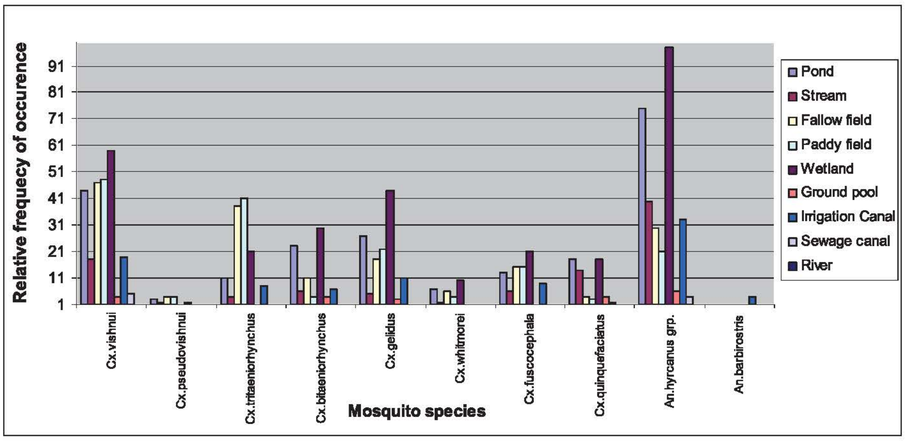

Figure 1: Relative frequency of occurrence of mosquito species

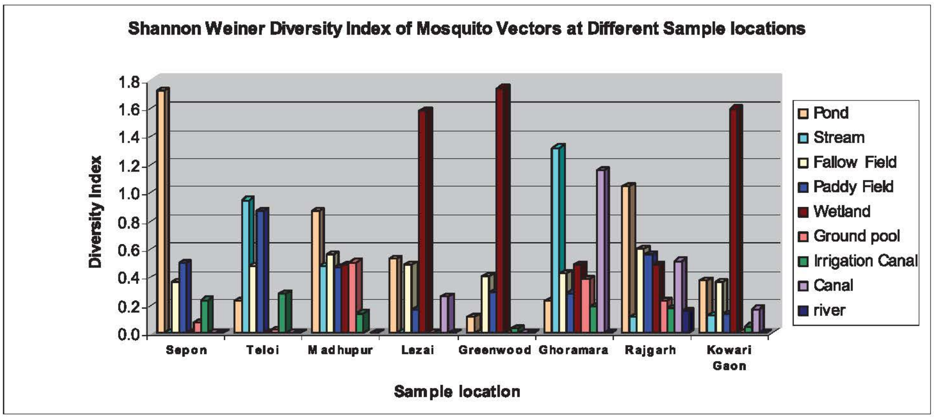

Figure 2: Shannon Weiner Diversity Index of vectors Mosquito at different sample location points

3.3 Forecasted and Observed JE Cases during Past Five Years

Integration of vector abundance map with map of host abundance and map of disease intensity lead to preparation of final map of JE risk viz. High, Medium and Low JE risk villages. Figure 3 depicts the map of JE risk for Dibrugarh district along the village wise reported JE cases for the year 2012. Graphs given in Figure 4 shows the number of JE cases reported from three different categories of JE risk villages during past five years (2008-2012). Highest accuracy in terms of forecasting JE prone villages was observed during 2010 and 2012 with 81% cases reported from High Risk villages forecasted under the study. Lowest accuracy were observed during 2011, when 70% cases reported from High Risk villages.

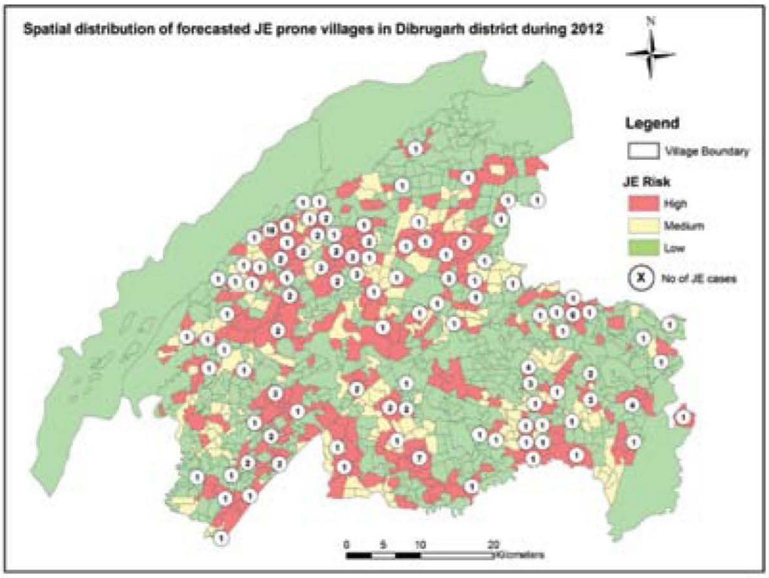

Figure 3: Forecasted and reported JE cases in Dibrugarh district during 2012

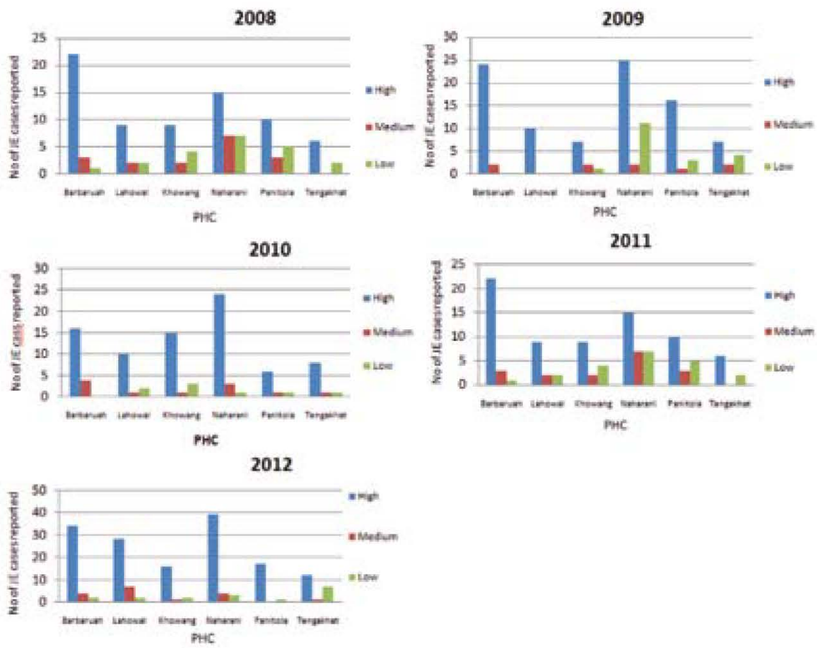

Figure 4: Number of JE cases reported from different categories of JE forecasted villages during 2008-2012

4. Conclusion

The study shows the potential application of geospatial tools to forecast the spatial distribution of JE occurrence at village level. This will help health department authorities to prioritize their focus on these areas for taking timely intervention measures. It will also serve as baseline information in a particular point of time and will help in future planning and monitoring. Detail study in terms of vector dynamics, response of JE viruses to different host populations, its relation with weather parameters in the endemic villages may reveal the critical factors responsible for disease transmission and outbreak. The study shows limitation of forecasting incidence from historical morbidity patters along with landscape and socioeconomic parameters and indicates need for improving the early warning integrating other weather parameters. Role of environmental factors in modulating seasonal abundance of potential Japanese Encephalitis vectors may be very critical (Khan et al., 1996). Predicting JE disease seasons may also be possible like in case of Malaria using multi-temporal meteorological satellite sensor as discussed by Hay et al., (1998).

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